Atlantic States Marine Fisheries Commission

Shad and River Herring Management Board

May 5, 2021
10:30 – 11:30 a.m.
Webinar

Draft Agenda

The times listed are approximate; the order in which these items will be taken is subject to change; other items may be added as necessary.

1. Welcome/Call to Order *(J. Davis)* 10:30 a.m.

2. Board Consent 10:30 a.m.
   - Approval of Agenda
   - Approval of Proceedings from February 2021

3. Public Comment 10:35 a.m.

4. Review Technical Committee Progress on Board Tasks *(B. Neilan)* 10:45 a.m.
   - Consider Technical Guidance Document for Implementation of Amendments 2 and 3 to the Shad and River Herring Fishery Management Plan **Action**
   - Update on Methods to Evaluate Bycatch in Mixed-stock Fisheries in State Waters
   - Consider Technical Committee Recommendations on Addressing Fish Passage Performance **Action**

5. Consider Approval of Shad Habitat Plan Updates **Action** 11:15 a.m.
   - Review Technical Committee Recommendations *(B. Neilan)*

6. Other Business/Adjourn 11:30 a.m.

MEETING OVERVIEW

Shad and River Herring Management Board
May 5, 2021
10:30 a.m. – 11:30 a.m.
Webinar

Chair: Justin Davis (CT) Assumed Chairmanship: 2/21	Technical Committee Chair: Brian Neilan (NJ)	Law Enforcement Committee Representative: Gadomski (NY)
Vice Chair: VACANT	Advisory Panel Chair: Pam Lyons Gromen	Previous Board Meeting: February 4, 2021
Voting Members: ME, NH, MA, RI, CT, NY, NJ, PA, DE, MD, DC, PRFC, VA, NC, SC, GA, FL, NMFS, USFWS (19 votes)		

2. Board Consent

- Approval of Agenda
- Approval of Proceedings from February 4, 2021

3. Public Comment – At the beginning of the meeting public comment will be taken on items not on the agenda. Individuals that wish to speak at this time must sign-in at the beginning of the meeting. For agenda items that have already gone out for public hearing and/or have had a public comment period that has closed, the Board Chair may determine that additional public comment will not provide additional information. In this circumstance the Chair will not allow additional public comment on an issue. For agenda items that the public has not had a chance to provide input, the Board Chair may allow limited opportunity for comment. The Board Chair has the discretion to limit the number of speakers and/or the length of each comment.

4. Review Technical Committee Progress on Board Tasks (10:45-11:15 a.m.)
Background • In February 2021, the Board reviewed the TC recommendations for improvements to Amendments 2 and 3 to the FMP, which provide additional criteria to guide the development of SFMPs and Alternative Management Plans. The Board agreed with the TC recommendations and tasked them to develop a technical guidance document for use in SFMP development and evaluation (**Briefing Materials**). • The American Shad 2020 Benchmark Stock Assessment and Peer Review Report was accepted for management use in August 2020. The assessment found that American shad remain depleted on a coastwide basis, likely due to multiple factors, such as fishing mortality, inadequate fish passage at dams, predation, pollution, habitat degradation, and climate change. At the February 2021 meeting, based on the TC recommendation the Board tasked the TC with “developing methods to evaluate bycatch removals in directed mixed-stock fisheries in state waters in order to understand and reduce impacts to stocks outside the area where directed catch occurs.” The TC has formed a work group to address this task and has started gathering relevant data. • In February 2021 the TC also indicated that additional recommendations related to fish passage were being developed. In light of the assessment results, which showed that barriers to fish migration are significantly limiting access to habitat for American shad, the TC has

highlighted recommended Board actions to address fish passage impacts on population recovery (**Briefing Materials**).
Presentations • Technical Committee Progress on Board Tasks by B. Neilan
Board actions for consideration at this meeting • Consider approval of the Technical Guidance Document for Implementation of Amendments 2 and 3 to the Shad and River Herring Fishery Management Plan • Consider sending letters to relevant agencies to request prioritization of TC recommended actions related to fish passage

5. Consider Approval of Shad Habitat Plan Updates (11:15-11:30 a.m.) Action
Background • Amendment 3 to the Shad and River Herring FMP requires all states and jurisdictions to submit a habitat plan for American shad. A majority of the habitat plans were approved by the Board in February 2014, and it was anticipated that they would be updated every five years. • The states began the process of reviewing their American shad habitat plans and making updates in 2020, however, many states encountered delays due to COVID-19. At the February 2021 Board meeting the following habitat plan updates were approved: ME, NH, MD, NC, Savannah River, and GA. • The following shad habitat plans were submitted for TC review and Board consideration at the May 2021 meeting: MA, RI, CT, Delaware River, SC, and FL (**Briefing Materials**). The remaining states will provide their updated plans to the TC for review before the next Board meeting. • The Technical Committee reviewed these habitat plan updates via email and recommends Board approval (**Supplemental Materials**).
Presentations • Shad Habitat Plan Updates for Board Consideration by B. Neilan
Board actions for consideration at this meeting • Consider approval of updated shad habitat plans for MA, RI, CT, Delaware River, SC, and FL

6. Other Business/Adjourn

Shad and River Herring 2021 TC Tasks

Activity level: Medium

Committee Overlap Score: Medium (Multi-species committees for this Board)

Committee Task List
• Board task to develop methods to evaluate bycatch removals in directed mixed-stock fisheries in state waters • Spring 2021: Updates to state Shad Habitat Plans • Annual state compliance reports due July 1
TC Members: Mike Brown (ME), Mike Dionne (NH), Brad Chase (MA), Patrick McGee (RI), Jacque Benway Roberts (CT), Wes Eakin (Vice Chair, NY), Brian Neilan (Chair, NJ), Josh Tryninewski (PA), Johnny Moore (DE), Rob Bourdon (MD), Ellen Cosby (PRFC), Joseph Swann (DC), Eric Hilton (VA), Holly White (NC), Jeremy McCargo (NC), Bill Post (SC), Jim Page (GA), Reid Hyle (FL), Ken Sprankle (USFWS), Ruth Hass-Castro (NOAA)

DRAFT PROCEEDINGS OF THE

ATLANTIC STATES MARINE FISHERIES COMMISSION

SHAD AND RIVER HERRING MANAGEMENT BOARD

Webinar
February 4, 2021

These minutes are draft and subject to approval by Shad and River Herring Management Board.
The Board will review the minutes during its next meeting.
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INDEX OF MOTIONS

1. **Approval of Agenda** by Consent (Page 1).

2. **Approval of Proceedings of August 2020** by Consent (Page 1).

3. **Move to task the Technical Committee with developing methods to evaluate bycatch removals in directed mixed-stock fisheries in state waters in order to understand and reduce impacts to stocks outside the area where directed catch occurs** (Page 14). Motion by Joe Cimino; second by Justin Davis. Motion carried (Page 15).

4. **Move to task the Technical Committee with developing a technical guidance document to guide SFMP/AMP development and evaluation based on the recommendations presented today.** (Page 24). Motion by Justin. Davis; second by Doug Haymans. Motion carried (Page 27).

5. **Move to approve the updated shad habitat plans submitted by ME, NH, MD, NC, SC, and GA** (Page 29). Motion by Cheri Patterson; second by Doug Haymans. Motion carried (Page 29).

6. **Move to approve the FMP Review for the 2019 fishing year, state compliance reports, and *de minimis* requests from ME, NH, MA, and FL** (Page 31). Motion by John Clark; second by Cheri Patterson. Motion carried (Page 31).

7. **Move to approve nominations to the Shad and River Herring Advisory Panel for Dr. Ed Hale from Delaware, and Eric Roach from New Hampshire** (Page 31). Motion by Justin Davis; second by Roy Miller. Motion carried (Page 32).

8. **Move to adjourn** (Page 32). Motion by Tom Fote; second by Allison Colden. Motion carried (Page 32).

ATTENDANCE

Board Members

Megan Ware, ME, proxy for P. Keliher (AA)
Cheri Patterson, NH (AA)
Ritchie White, NH (GA)
Mike Armstrong, MA (Chair)
Raymond Kane, MA (GA)
Rep. Sarah Peake, MA (LA)
Phil Edwards, RI, proxy for J. McNamee (AA)
David Borden, RI (GA)
Eric Reid, RI, proxy for Rep. Sosnowski (LA)
Justin Davis, CT (AA)
Robert LaFrance, CT, proxy for B. Hyatt (GA)
Maureen Davidson, NY, proxy for J. Gilmore (AA)
John McMurray, NY, proxy for Sen. Kaminsky (LA)
Joe Cimino, NJ (AA)
Tom Fote, NJ (GA)
Adam Nowalsky, NJ, Legislative proxy (Chair)
Kris Kuhn, PA, proxy for T. Schaeffer (AA)
Loren Lustig, PA (GA)
G. Warren Elliott, PA (LA)
John Clark, DE, proxy for D. Saveikis (AA)
Roy Miller, DE (GA)
Craig Pugh, DE, proxy for Rep. Carson (LA)
Lynn Fegley, MD, proxy for B. Anderson (AA)
Russell Dize, MD (GA)
David Sikorski, MD, proxy for Del. Stein (LA)
Pat Geer, VA, proxy for S. Bowman (AA)
Chris Batsavage, NC, proxy for J. Batherson (AA)
Ross Self, SC, proxy for P. Maier
Malcolm Rhodes, SC (GA)
Chris McDonough, SC, proxy for Sen. Cromer (LA)
Doug Haymans, GA (AA)
Spud Woodward, GA (GA)
Erika Burgess, FL, proxy for J. McCawley (AA)
Marty Gary, PRFC
Max Appelman, NOAA
Mike Millard, US FWS

(AA = Administrative Appointee; GA = Governor Appointee; LA = Legislative Appointee)

Ex-Officio Members

Brian Neilan, Technical Committee Chair
Larry Furlong, Law Enforcement Representative
Pam Lyons Gromen, Advisory Panel Chair

Staff

Bob Beal
Toni Kerns
Maya Drzewicki
Kristen Anstead
Pat Campfield
Emilie Franke
Lisa Havel
Chris Jacobs
Jeff Kipp
Laura Leach
Sarah Murray
Mike Rinaldi
Julie Simpson
Caitlin Starks
Deke Tompkins
Geoff White

Guests

Karen Abrams, NOAA
Fred Akers
Katie Almeida
Bill Anderson, MD (AA)
Pat Augustine, Coram, NY
Michael Auriemma, NJ DEP
Jason Bartlett, ME DMR
John Bartolo
Mike Bednarski, VA DGIF
Dave Behringer, NC DENR
Mel Bell, SC DNR
Alan Bianchi, NC DNR
Rob Bourdon, MD DNR
Michael Brown, ME DMR

Guests (continued)

Delayne Brown, NH F&G
Jeff Brust, NJ DFW
Benson Chiles, Chiles Consulting
Richard Cody, NOAA
Allison Colden, CBF
Heather Corbett, NJ DEP
Rip Cunningham, TRCP
Jessica Daher, NJ DEP
Randy Dean
John DePersenaire, RFA
Greg DiDomenico
Chris Dollar, Queenstown, MD
Frazier Dougherty
Wes Eakin, NYS DEC
Julie Evans
Sheila Eyler, US FWS
Cynthia Ferrio, NOAA
James Fletcher, Wanchese Fish Co
Dawn Franco, GA DNR
Toni Friedrich, SGA
Alexa Galvan, VMRC
Matt Gates, CT DEEP
Lewis Gillingham, VMRC
Jim Gilmore, NYS DEC
Angela Giuliano, MD DNR
Zoe Goozner, Pew Trusts
Emily Hall, Seatuck
Helen Takade-Heumacher, FL FWS
Greg Hinks, NJ DEP
Carrie Hoover, MD DNR
Asm. Eric Houghtaling, NJ (LA)
Rachel Howland, NC DENR
Stephen Jackson, FL FWS
Jeff Kaelin, Lund's Fisheries
Desmond Kahn
Greg Kenney, NYS DEC
Adam Kenyon, VMRC
Craig King, ME DMR
Wilson Laney
Edward Leonard, GA DNR
Tom Little, NJ LEG
Chip Lynch, NOAA
John Maniscalco, NYS DEC
Genine McClair, MD DNR
Margaret McGinty, MD DNR
Dan McKiernan, MA (AA)
Nichola Meserve, MA DMF
Steve Meyers
Chris Moore, CBF
Patrick Moran, MA Env. Police
Jerry Morgan
Clinton Morgeson, VA DWR
Brandon Muffley, MAFMC
Kennedy Neill, Yorktown, VA
Gerry O'Neill, CapeSeafoods
Derek Orner, NOAA
Ian Park DE DFW
Alexis Park, MD DNR
Thomas Paulson, NC DENR
Rich Pendleton, NYS DEC
Nicholas Popoff, US FWS
Bill Post, SC DNR
Harry Rickabaugh, MD DNR
Andrew Sinchuk, NYS DEC
Brandi Salmon, NC DENR
Erik Schneider, RI DEM
McLean Seward, NC DENR
Thomas Sminkey, NOAA
Somers Smott, DMRC
Renee St. Amand, CT DEEP
John Sweka, FL FWS
Jim Uphoff, MD DNR
Chris Uraneck, ME DMR
Mike Waine, ASA
Holly White, NC DENR
Kerry Whittaker, MMA
Kate Wilke, TNC
Josh Winger, NC DENR
Chris Wright, NOAA
Sarah York, NOAA
Renee Zobel, NH F&G

The Shad and River Herring Management Board of the Atlantic States Marine Fisheries Commission convened via webinar; Thursday, February 4, 2021, and was called to order at 8:30 a.m. by Chair Michael Armstrong.

CALL TO ORDER

CHAIR MICHAEL ARMSTRONG: Good morning everyone, this is Mike Armstrong from Massachusetts, your Board Chair for today for the Shad and River Herring Board. We have three hours today, which is a good amount of time, but we do have a lot of items. It may go fast, but may generate a lot of discussion also.

APPROVAL OF AGENDA

CHAIR ARMSTRONG: First task is we have an Agenda, does anybody have amendments, additions?

MS. TONI KERNS: I don't see any hands for any changes or additions.

CHAIR ARMSTRONG: No hands, then we will consider the agenda approved by consensus.

APPROVAL OF PROCEEDINGS

CHAIR ARMSTRONG: You all have a copy of the proceedings from last meeting, any edits?

MS. KERNS: I do not see any hands for edits.

CHAIR ARMSTRONG: All right, thank you. We will consider the minutes from August 2020 accepted by consensus.

PUBLIC COMMENT

CHAIR ARMSTRONG: The next is Public Comment. Again, we solicit comments at the beginning of the meeting on items that will not be considered during the agenda. Are there any members of the public that would like to speak, and it needs to be brief, maybe a minute or so?

MS. KERNS: As a reminder for members of the public, in order to raise your hand, you click on the hand icon. When the red arrow is pointing down your hand is up, and I see no members of the public with their hands raised, Mr. Chairman.

CONSIDER MANAGEMENT RESPONSE TO THE 2020 SHAD BENCHMARK ASSESSMENT AND PEER REVIEW

CHAIR ARMSTRONG: All right, thank you, Toni. Moving to Item 4. Consider a Management Response to the 2020 Shad Benchmark Assessment and Peer Review.

TECHNICAL COMMITTEE RECOMMENDATIONS

CHAIR ARMSTRONG: First, we'll have a review of the Technical Committee advice by Brian Neilan, Brian, take it away.

MR. BRIAN NEILAN: Thank you, Mr. Chair, and good morning to the Board. You'll be hearing a couple presentations from me today. First will be Technical Committee recommendations on improving shad stocks. Just a quick outline of this presentation for today. First, we'll go over the background on the Board task, and both the specific and coastwide TC recommendations, and finally, the next steps for going forward.

Some background on the Board task. The American shad benchmark stock assessment and peer review was accepted by the Board back in August of 2020. The assessment found that American shad remained depleted on a coastwide basis, and found unfavorable stock status for several system-specific stocks. Given these findings, the Board tasked the TC with identifying potential paths forward to improve shad stocks along the coast, considering the results of the assessment. This is from the assessment results.

The TC decided to focus on systems with either unsustainable or depleted stock status, or systems that had fisheries, and had an unknown stock status. This table shows those systems, their stock statuses, and what type of fisheries are currently executed within them. There is an asterisk there for South Carolina.

South Carolina has several systems within it that were assessed, including the Winyah Bay, Santee Cooper, and eight basin systems. You all can see the coastwide finding as well, which is depleted. First, we'll go over the TC system-specific recommendations, focusing on systems with unsustainable or depleted findings.

For each system we'll have a slide with the TCs recommendations, and then one slide with the rationale behind those recommendations. Starting with the Connecticut River, which was found to have an unsustainable adult mortality. The TC has recommended that agencies involved continue to monitor the Connecticut River's SFMP metrics, and implement appropriate management responses if any of the benchmarks are triggered.

Additionally, collaborative work with the Connecticut River Atlantic Salmon Commission partners should be undertaken, to realize continued passage and habitat improvements. The final recommendation for the Connecticut River would be to explore alternative survey methods, in order to provide the recreational effort and harvest estimates, which we currently don't have for the Connecticut River.

Here is their rationale for the Connecticut River recommendations. There is an increasing trend in adult shad counts at the fish lift over the past 12 to 15 years. The metrics from the Connecticut River's SFMP have continued to remain above target levels. Collecting accurate recreational effort and harvest data will help quantify the recreational fisheries effect on adult mortality.

Finally, given the relatively low harvest rates, it's believed that any changes to the fishery will have minimal effects on stock recovery. There were only about 5,500 pounds of shad landed in 2019, which I believe was the time series low, and it's been part of a continued declining trend in the recent past.

High downstream mortality at hydropower facilities and other associated factors is thought to be more likely the primary sources of mortality, rather than the fishery. That is the Connecticut River. For the Delaware River, which was also found to have an unsustainable adult mortality. The TC recommends no monitoring or management changes for the 2021 fishing season.

The Delaware River SFMP should be revised to include updated data methods, and results from the 2020 stock assessment. Finally, the Delaware SFMP should incorporate a management response to be triggered by an unsustainable adult mortality determination from the stock assessment, though mostly incorporating stock assessment work into their upcoming SFMP update. The rationale here is that the Delaware River SFMP is due to be updated by the end of 2021, as it's nearing the end of its five-year tenure. It didn't really make sense to change things this year, with possible changes coming up at the end of the year anyway.

This process will allow TC input and evaluation of potential management measures in the updated plan. That is the rationale for the Delaware River. We can go to the Potomac next. For the Potomac River, which had an unsustainable adult mortality finding. The TC recommends the continued prioritization of conservation of natural land cover throughout the lower Potomac watershed, as well as an expansion of commercial and recreational fisheries on non-native predators, such as blue catfish and flathead catfish.

These species are thought to be a significant source of mortality for both shad and river herring. Additionally, it's recommended that steps be taken to identify the contribution of Potomac River origin shad, and mixed-stock fisheries as well as in the ocean bycatch. This is in order to reduce or eliminate harvest of Potomac River origin shad in these fisheries.

Since this is kind of outside the Potomac's jurisdiction, it will require coordination between the states, ASMFC, and regional councils. For the rationale for the recommendations for the Potomac. It has been shown that there is an increase in trends in the Potomac Pound Net TPU Index. There is flying stock survey, as well as their juvenile survey, so you have increasing trends there, which is nice to see.

The ASMFC American Shad Restoration Target for the Potomac River was exceeded again in 2019, which is the ninth year in a row their restoration numbers have been above the target. Officially, the TC is concerned with further restricting the limited bycatch fishery they have, and any brood stock removals for hatcheries.

That could result in reduced data availability for future assessment. That is where we get a lot of our biological aging data, and this would likely not have a significant impact on the stock. That is the rationale for the Potomac, move on to the Hudson. Here we had the recommendations for the Hudson River, which had a stock status finding of depleted.

The first recommendations, similar to the Potomac, is to identify stock composition and ocean bycatch in the mixed-stock fleet fisheries, and to seek to reduce or eliminate these sources of Hudson-specific mortality. Again, this will require coordination between the states, ASMFC, and the regional councils.

Also, New York should implement habitat restoration actions identified in the Hudson River Estuary Habitat Restoration Plan. The idea here is that will restore high quality spawning, nursery and refuge habitats. The final recommendation for the Hudson is to continue the fishery closure until the stock recovers to a level that could support sustainable harvest.

The rationale for the Hudson recommendations is that there is currently no fishery, so continue that closure. If there is no fishery there is obviously not a source of mortality there. That is why we have the emphasis on addressing habitat issues and out of basin harvest, and sources of mortality. The previous slides were systems with unsustainable or depleted status findings. The following systems have recreational harvest, commercial harvest, or both. During this assessment they had an unknown mortality or stock status determination. Starting with Maine, which allows the recreational harvest of 2 shads a day.

The recommendation is to work towards removing barriers to upstream passage, either through dam removal, fishway installation, or improving current fishways, in order to improve passage efficiency. The goal being to increase abundance, and provide opportunity at these fishways to collect biological data for aging and mortality estimates.

Their rationale for Maine, the rationale being there were insufficient data to make a stock status determination, given the data vetting criteria of the stock assessment. They just didn't have biological data to come up with a status, and there is currently limited potential to improve biological data using small run sizes. We need to work towards improving their data collection.

We have the Merrimac River. For the Merrimac River, where recreational harvest of three shad per day is allowed. The recommendations include addressing concerns with data time series and age sample sizes, in order to produce mortality estimates. The time series or sample sizes just didn't meet the minimums for this assessment to develop a mortality estimate.

Also, improving repeat spawning ratio data time series through ongoing shad scale collection and aging. Continue annual reviews of hydro-power dams, to identify passage impacts, and recommend improvements, possibly as part of FERC relicensing agreements and requirements. Lastly, it's recommended that a juvenile abundance index be developed to complement the adult indices.

The rationale for the Merrimac recommendations is that there was insufficient data to determine abundance status, due to low age samples in some years, preventing the calculation of mortality estimates. Just for a reference, the spawning runs sustainability benchmark has been achieved as of late, and is having an increasing trend on the Merrimac.

In North Carolina, with the Tar-Pamlico and Cape Fear Rivers, there were no recommended actions at this time. In the Tar-Pamlico system female relative F has remained well below the threshold since 2013. This is consistent with the decline in commercial landings. Female abundance index was below the threshold in the last two years.

In the Cape Fear there is an increasing trend in adult abundance, likely a sign of improved passage, and their SFMP. SFMP metrics for female relative abundance, and F has not exceeded thresholds since 2011 and 2012. Additionally, juvenile abundance sampling for striped bass was initiated in 2017, so that could possibly be a use for a juvenile shad abundance index in the future, in upcoming SFMPs and assessments.

For the rivers in South Carolina, where recreational and commercial harvest is permitted, there are no recommended changes to the monitoring or management requirements at this time, beyond continuing programs and sampling efforts currently underway in these systems. This is to expand timeseries to a length consistent with the stock assessment research recommendations. Additionally, it was recommended that paired otolith and scale samples should be collected. The rationale here for these recommendations in South Carolina, is that their conflicting trend in the Winyah Bay and Santee Coper systems and no trends in the eight-basin system in their adult abundance indices.

All data time series for their young of year electrofishing surveys will meet assessment thresholds for the next assessment. They were just too short to be used for this one. For the Savannah River, which allows recreational and commercial harvest. The recommendations are the same as the other South Carolina systems, including continuing the timeseries of the current surveys to meet minimum assessment requirements, collecting biological samples for aging.

Again, the same rationale for the Savannah River as the other South Carolina rivers, including conflicting trends in abundance indices, and that had shorter than required time series for the purposes of this assessment. For the Altamaha in Georgia, which allows commercial and recreational harvest, you see the same recommendations here, including continuing the timeseries to meet assessment minimums, and collecting biological samples for aging.

Similar rationales as well, with no detectable trends in adult abundance indices, and data time series that didn't quite meet the minimum as required for this assessment. In Florida, with the St. Johns River, where recreational harvest of shad is allowed, there are no recommended changes to the management and monitoring requirements, beyond improving monitoring data, by accounting for environmental variability effects.

I believe the catchability in their survey is heavily influenced by flooding, if it's a flood year, looking into accounting for flow rates in developing their indices, as well as using age data to identify year class and maturity schedule. Some of the rationale for the St. Johns, the young of year and spawning stock indices showed no trend, and an increasing trend respectively at a mean fork length of males and females, both showed increasing sizes over time.

Additional data otoliths for age composition and size at age will reach the timeseries threshold of ten years, and be available for the next assessment. Recreational harvest is the only known source of American shad removal within the St. Johns. Those were the system-specific recommendations. Now we're going to move on to the coastwide recommendations.

The first recommendation from the TC is further action is needed to improve fish passage and passage mortality poses a substantial threat to shad stocks, and limits recovery potential as evidenced through the stock assessment. The TC is currently preparing a memo with recommendations for the Board related to shad passage, it just wasn't quite ready for this meeting.

Going forward, paired otoliths and scale samples should be collected in all systems where it is possible. Otoliths are currently the preferred structure, but not necessarily everyone is collecting otoliths, due to a variety of reasons. States should aim to improve surveys to increase survey power to detect trends. Many datasets with sufficient time series were included from the final assessment, due to a lack of power to detect a 50 percent trend, changing trend up or down over a ten-year period, which was the minimum criteria for this assessment. The TC also recommended that system-specific restoration targets should be developed where appropriate, and where we have the data to do so, or be revisited where they already exist, to provide measurable goals for evaluating recovery efforts. Additionally, the TC recommends the Board task them with developing alternative methods to evaluate bycatch rules, and removals in directed mixed-stock fisheries in state waters.

This is in order to understand and reduce impact to external stocks of directed mixed-stock fisheries, such as Hudson River shad caught in the Delaware Bay. The TC also identified two priority research recommendations, which they felt were related to this Board task. First, is conducting annual stock composition sampling through existing or new observer programs from all mixed stocks and bycatch fisheries.

Second, otoliths should be collected as the preferred age structure. Collection of otoliths presents a perceived impact due to the conservation of the stock, since it's a source of mortality that sort of sampling, or it's just generally not feasible. An annual subsample of paired otoliths and scales should be collected. They are looking at 100 plus samples to quantify error between structures.

Those are the priority research recommendations. Next steps, we have a Board action for consideration, mainly tasking the TC with developing alternative methods to evaluate bycatch removals in directed mixed stock fisheries in state waters. That is what we have for this presentation.

CHAIR ARMSTRONG: Thank you, Brian. I think what we're going to do, we'll move right into the Advisory Panel Report, and we can address questions to both Pam and Brian at the same time. But I would like to thank the Technical Committee, their task is always huge, because they have to go through so many systems separately. It's a whole different way of operating, and a lot more work, so thank you to the Technical Committee.

ADVISORY PANEL REPORT

CHAIR ARMSTRONG: We'll get the Advisory Report now from Pam Lyons Gromen. Pam.

MS. PAM LYONS GROMEN: Thank you, Mr. Chairman, and good morning everyone. I will be providing the Advisory Panel comments in response to the Technical Committee recommendations. The AP actually had a chance to meet twice since the Board last convened in August. We met in October, and we reviewed an initial draft of the TC recommendations.

Then we met again in January, to look at a near final draft, and that draft included more coastwide recommendations. The attendees that came to our AP meeting included representatives from New Hampshire, New York, New Jersey, Delaware, North Carolina, and our non-traditional stakeholders.

I'll just say that it was nice to have Dr. Ed Hale and Mr. Eric Roach, who are candidates for the AP, just jump right in and join us for these discussions. I'll start with the system-specific discussions and recommendations that we had. We talked about the Hudson River, which as you know the status is depleted. There was general support for the TC recommendation, although the high priority recommendation of reducing and eliminating ocean bycatch may be challenging, and it is unclear how this will be done. For the Delaware River Basin, and that status is on sustainable adult mortality. Concerns were raised about the surveys that were used to estimate the Delaware Bay mortality in the assessment. These were the Smithfield Beach Gillnet Survey, the Lewis Haul Seine Fishery Survey, and the Lehigh River Electrofishing Survey. Our representative from Delaware felt like none of these surveys really are adequately designed and executed for assessing mortality or stock status.

The recommendation was that the Delaware River Coop explore other existing monitoring surveys for assessing stock status, such as the DNRAC trawl survey, and to consider reprioritization addition or deletion of the currently used indices, to assess stock status in the Delaware Basin FMP.

For the Tar-Pamlico and Cape Fear, the status there again was unknown, but there are active fisheries. The TC recommendation for no changes to management was deemed acceptable by the AP, as long as no additional fishing pressure is added. But concerns were expressed that additional information for the Tar-Pamlico and the Cape Fear system could have been included in the assessment.

Otolith sampling, we had a good discussion about this, recognizing the importance in the research recommendation, that the sampling target should be better defined for the various data sources, that it's going to be specific stock, fishery independent versus dependent surveys, how they are going to be collected, in order to ensure that these otolith sampling can be completed to meet the assessment needs.

There was also concern raised about the recommendation to collect 100 otolith samples. It was unclear to us whether this was for a coastwide collection or for each system, or for each state, but may be challenging if this is 100 samples from each state. We had a pretty good discussion about the coastwide recommendations, and so this addresses the mixed-stock fisheries, and also the ocean bycatch.

The AP discussed the importance of the genetic data, to characterize stock composition in the Delaware Bay mixed-stock fishery, and in ocean bycatch. Genetic information is a major data gap in the assessment. All AP members agree that the Board should support, however possible, the USGS project to develop a genetic repository for alosine species. The AP also felt that the Commission should reach out to the Northeast Fishery Observer Program, to ask that they prioritize sampling of shad in federal fisheries bycatch.

Finally, the data from the shore-side monitoring program, which is performed by the Massachusetts Department of Marine Fisheries, should be incorporated in the next assessment to improve information on ocean bycatch. We talked about data gaps in the assessment, and the AP flagged the following issues as notable data gaps that are in need of the Board's attention.

That would be juvenile mortality estimates, information to quantify recreational effort, harvest, and incidental mortality on a coastwide spatial scale, noting that MRIP does not sample those upper stretches of tributaries that are important. Reporting of incidental catch in recreational and commercial fisheries from all systems, including the coastal waters. Bycatch should be documented and reported, even if the current stock status in a system is deemed sustainable. Finally, environmental information like climate, streamflow, and water quality. We spent a bit of time talking about climate change, because American shad have been classified as highly vulnerable to climate change, and this is an issue that needs to be prioritized and addressed in future work in assessments.

Communication between the Commission and federal partners about climate impacts could be improved to better define how information is shared between partners, and taken into account by fishery managers. An example that was raised was the American shad distribution shifts, which are currently mapped on the Mid-Atlantic Ocean Data Portal. They could be used traps for better understanding and mitigating the impacts caused by bycatch on mixed stocks and in the ocean. I believe that is my last slide. Yes, questions. That's the end, thank you, Mr. Chairman.

CHAIR ARMSTRONG: Thank you, Pam, and again thank the Advisory Panel for a really thorough review of this. At this time, does anyone have any questions for either Brian or Pam?

MS. KERNS: You have Lynn Fegley and Justin Davis, and then Joe Cimino.

CHAIR ARMSTRONG: Okay, Lynn Fegley.

MS. LYNN FEGLEY: Good morning everyone, and thank you, Pam, thank you both for the excellent presentations. It really is a lot of work to get through those. I just had two quick questions, Pam, about your presentation. The first was this confusion about the 100 otolith samples, whether that's for each state or coastwide.

That seems like a pretty easy question for the TC to answer, so if we could get an answer to that, I think that would be helpful. My second question was, with the Advisory Panel's suggestion to within the Northeast Fishery Observer Program to prioritize the sampling of shad by catch. Does that mean prioritize for genetic sampling, or does that mean just prioritize the quantification and size structure and such? Thanks.

MS. LYONS GROMEN: Thank you for those questions. Yes, I believe that the discussion was about how when the Observer Program collects samples that they really do have to prioritize. They can't really take samples of everything. Shad may not be a priority for them at the moment, but if it was communicated to them, then they could collect shad for a variety of purposes. I believe it could be for otoliths.

It certainly could be looking at its size and age structure. But certainly, the genetics, the value of genetics and providing samples to the USGS for their catalogue they are putting together. That was all a big part of our discussion. I think the genetic material as we try to understand how ocean fisheries are impacting individual stock is very important. Thank you.

MS. CAITLIN STARKS: Brian, I don't know if you want to jump in and answer the second part of that question about the otolith sampling, or I can.

MR. NEILAN: Sure. I'm under the impression from the TC that it's going to be system-specific that 100 samples.

MS. STARKS: I can verify that as well.

CHAIR ARMSTRONG: All right, thank you, Brian. Toni, I missed the second person in line.

MS. KERNS: We have more people on the list.

CHAIR ARMSTRONG: Okay, so Justin was next?

MS. KERNS: I think so, and then Joe Cimino, Marty Gary, John McMurray, and Malcolm Rhodes.

CHAIR ARMSTRONG: Justin, go ahead.

DR. JUSTIN DAVIS: Thank you Brian and Pam for these presentations this morning. I've a question directed towards Brian, having to do with the recommendation by the TC to focus on further passage improvements along the coast, and the idea that passage mortality poses a substantial threat to shad stocks right now.

I guess I just wanted to clarify. Is the focus there on improving existing passage facilities at barriers along the coast, because the thought is that mortality occurring at those passage facilities is a problem, or is it more focusing on establishing new fish passage, or the combination of the two? The reason I'm asking is because it has been my experience here in Connecticut that establishing upstream passage at a dam, without providing for adequate downstream passage, or even establishing upstream passage.

It doesn't work well for shad, can actually be sort of a net negative. You would be better off just not having the passage in place, and subjecting the fish to the poorly constructed upstream passage, or putting them upstream where the juveniles can't get back downstream. I guess I just wanted to clarify what the TCs focus is there, thanks.

MR. NEILAN: Thanks for that question. Yes, I think the TC, it's going to be a combination of the two. Obviously putting in fish passage or removing dams, putting in fish passage generally where it's not already, is obviously going to be a good thing. But I know, like you said, a lot of fish passage structures, some are not efficient. I know in New Jersey some don't work at all. It's working towards setting possible, you know efficiency targets for moving shad both up, adults up, and reducing mortality of adults and juveniles going down.

CHAIR ARMSTRONG: Joe Cimino.

MR. JOE CIMINO: I kind of lost my question in the process. It was the same as the Aps and Lynn's question regarding the otolith collection. If you will humor me, I may move it to a bit of a comment in that, perhaps the TC could review effective sample sizes for some of these systems. Maybe that 100 otolith number, which might be very difficult to get. You may find that another number is at least sufficient, so just kind of a recommendation for the future for that. Then when you're ready, I will have a motion. Thank you.

CHAIR ARMSTRONG: We'll come back to that motion. Marty Gary.

MR. MARTIN GARY: Thank you Brian and Pam for your presentations this morning. My question is also for Brian. I noticed on the slide that you put up, Brian, that it mentions the elimination and reduction of our bycatch fishery, but you didn't mention it, and I think I know why, because the TC had the discussion back in August of last year.

I had asked Dr. Limburg, who presented the Peer Review report what the value would be of that dataset, it's over two decades long. She indicated at that time that you wouldn't want to compromise that dataset. Those discussions, I was aware were engaged at the TC level, and it was decided that we would continue the bycatch.

But the Board was listed in the presentation, still, and I just wanted to be sure that was the case. We view the elimination and reduction of that as antithetical to increasing our knowledge base for this species in the Potomac. I just want to be sure, Brian, that was the conversation you all had at the TC. Thank you.

MR. NEILAN: Yes, that is what we're working towards. I guess the rationale here is, it's generally accepted that out of basin harvest is undesirable, but we don't have a grasp on what degree mixed-stock harvest is affecting out of basin fisheries, especially considering from the assessment that there is no responsive shad, or little to no responsive shad to the closing of the intercept fisheries. This is probably a number one topic right now in discussion among the TC. It's getting an understanding of these mixed-stock fisheries, and how to move forward with them in the future. I'm not sure if I answered your question there.

MR. GARY: Yes, I think so, Brian, thanks, and quick follow, Mr. Chairman. Just so everybody knows, Brian also mentioned that we have been plotting our CPUEs from that bycatch fishery against a target restoration rate. That target is based on catch per unit effort from my Walburg and Sykes Survey by the U.S. Fish and Wildlife Service. It may have been the predecessor of the U.S. Fish and Wildlife Service. This goes back into the 1940s.

It was deemed to be a good timeseries, a good survey to match up against. We've been exceeding that value for many years. The discussion was pretty perplexing to us, you know when the benchmark came out. But we understand all this uncertainty that is swirling around the species, especially in the adult phase and what may or may not be going on the coast, what may or may not be happening in terms of predation in the early life stages.

We have a prodigious blue catfish and base of blue catfish problem in the Potomac, as is in a lot of parts of the Chesapeake Bay. There are a number of factors that could be contributing, but we just saw the value of continuity of the bycatch fishery. My understanding of it is that the TC was in agreement that that would continue, so thank you.

CHAIR ARMSTRONG: I have John McMurray.

MR. JOHN G. McMURRAY: On the Hudson River system slide, the TC identified reducing or eliminating bycatch in mixed-use fisheries, as well as identifying stock composition of bycatch occurring in federal waters, and quantifying that in fact. The AP seemed to focus on this also. My question is how do you address bycatch in mixed-stock fisheries? How do you address ocean bycatch in federal waters, which seems to be the goal here? As you know, the Council attempted to do that, I think six, or maybe seven years ago with a bycatch cap. But are there other methods being discussed that I'm not aware of?

MR. NEILAN: I think yes, it is going to be certainly difficult, especially in the ocean bycatch fishery. I think right now we're at the kind of exploration of methods point, especially nailing down the genetics or teasing out the genetic composition on a stock-by-stock basis of each stock's representation. It is certainly easier to do within state waters.

Like in Delaware Bay there is currently a benchmark, a management trigger associated with the mixed-stock fishery that's taking place down there in the lower Bay through a genetic work and tagging work. It has been determined that 40 percent of the mixed-stock fishery in the lower Bay is Delaware Basin fish. A certain target has been made with a certain percentage of the total harvest exceeds the 60 percent of everything else.

There would be some management action in the lower Bay; closure of the fishery, gear restrictions, area restrictions. That's just kind of an example of what is currently being done, at least in a mixed-stock fishery. As far as the ocean bycatch, you mentioned catch caps. I'm not sure how effective they are, given how many stocks we're working with here. It's a difficult question, for sure.

MS. STARKS: If I could just follow up, Mr. Chair, this is Caitlin.

CHAIR ARMSTRONG: Please.

MS. STARKS: I just wanted to note also that the Technical Committee is recommending that they work on developing methods to evaluate bycatch, because they are currently recognizing that right now it's difficult, and they would like to try to be able to better understand what impact the Delaware Bay fishery, for example, is having on stocks outside of that system. But right now, they don't have a way of doing that. That is what that task is being recommended for.

MR. McMURRAY: Thanks for the answer. What about federal waters? How do you identify stock composition? Is there sampling going on or are you planning on doing that, or is that aspirational?

MR. NEILAN: I don't believe there is genetic sampling going on right now. That would be something that the Board here would have to work with the Council, in order to make that a priority going forward. I know the U.S. Fish and Geological Survey is working on creating a database for stock-specific genetic alosine sampling, and having that as a repository to compare against. But I don't believe there is any current genetic sampling on the ocean bycatch right now for shad.

CHAIR ARMSTRONG: Malcolm Rhodes next.

DR. MALCOLM RHODES: Pam and Brian, thank you and your Committees for the presentations, they were very insightful. Pam, I have a possibly quick question. At the end of your report, you stated that shad are highly vulnerable to climate change, and I was just wanting a little elucidation.

Given their history, is the concern that return to the natal rivers it's too warm, or it's too much stress on the passage through warmer waters, or is this an effect up in Nova Scotia, Bay of Fundy area? Just interesting trying to tease out where the highly vulnerable to climate change comes from. Thanks.

MS. LYONS-GROMEN: Sure, thank you for the question. The Northeast Fisheries Science Center led work to do a climate vulnerability assessment for stocks in the greater Atlantic, and river herring and shad species were part of that assessment. I believe it's mentioned in the shad benchmark assessment as a reference, but certainly it's available online.

Their conclusions were that American shad, alewife, and blueback herring were all highly vulnerable. They ranked species to their vulnerability of climate change, and these species rose to the top. That's where that comment came from. In terms of the Mid-Atlantic Ocean data portal, they took a lot of information about distribution of American shad, as well as the river herring species, and plotted it historically, and this is ocean distribution.

Then they projected out into the future, based on some work with Rutgers and the National Marine Fisheries Service, and I believe also Canada was part of that work as well. You can see some pretty startling changes over time, looking at the effects of climate and ocean warming, and how these species have changed their distribution in the ocean. That's where that comment came from.

Certainly, are some smaller bodies of work out there looking at individual systems, and how climate has impacted their migration into its system to spawn, and also shortens their time in the spawning runs, and they don't have as much time any longer. I believe that work is available. Anyway, there is a lot of work there, and I think the APs point was that this really needs to be looked at a big more, and considered when we decide on management strategies to help conserve and bring back our American shad. Thank you.

CHAIR ARMSTRONG: Toni, are there any other Board members with questions?

MS. KERNS: Yes, you have Roy Miller, David Borden, Lynn Fegley, and Justin Davis. Then you do have a couple members from the public that have had their hand up.

CHAIR ARMSTRONG: Roy Miller, go ahead.

MR. ROY W. MILLER: Thank you Brian and Pam for your reports. Pam, I was particularly impressed with the Aps recommendations for improving surveys in the Delaware River. Having said that, I would like to probe a little bit about confidence of the Technical Committee in the genetic origin data for the mixed-stock fishery in lower Delaware Bay. It is unclear to me whether we have enough data in hand to take any management action, or whether it's a call for additional samples and on our need for greater reliability on that data than what we have at present. Brian, you may be the wrong one to direct this to. I might need to direct it to members of the Delaware River Fish and Wildlife Cooperative. But I'm wondering if you have any information on that particular mixed-stock fishery to share with us, in terms of how confident you are in the conclusions regarding the mixed-stock fishery in lower Delaware Bay.

MR. NEILAN: I would be happy to answer any question. I'm on the Coop, so I have a little more knowledge there. There has been a small study for genetic sampling that the Coop started around 2017. At this point we have three years of data, genetic sampling data. We're collecting genetic samples basically from the mouth of the Bay all the way up to Smithfield Beach, which is way up almost to New York.

We currently are sampling. I don't think we have enough data quite yet to base any management decisions on. U.S. Fish and Wildlife Service and Northeast Fisheries Science Center is doing our genetic analysis. Just to kind of give you an idea of the preliminary years of data, genetic composition of the lower Bay seems to match up with the different tagging studies. New Jersey conducts a tagging study of striped bass in the lower Bay, and we tag shad incidentally, and I believe Wogman did a study as well.

At least preliminary wise the genetic sampling seems to match up with what has been found in the tagging surveys. But I don't think we have the timeseries, or just the quantity and quality of data yet to decide management decisions off this. That's certainly a major impetus behind the TC requesting the Board task the TC with developing methods to evaluate genetic sampling and evaluating bycatch removals, not just in Delaware Bay, but in other mixed fisheries and the ocean fishery as well.

MR. MILLER: Thank you, Brian.

CHAIR ARMSTRONG: David Borden.

MR. DAVID V. BORDEN: Good morning. There are a number of references to hydropower impacts on the shad population. For instance, in the Connecticut River. My question is, to what extent do the hydropower companies have to provide funding to state agencies to assist with the monitoring and remediation program?

I recognize that there is a whole FERC process that gets superimposed over this. But it seems to me that the state agencies that are represented on this call are being asked to share a disproportionate burden, in terms of monitoring and management. Maybe if that is the case, maybe we could consider at some point including suggestions or recommendations in a letter to appropriate parties to remedy that situation. We've got a new administration in Washington, and they might be receptive to that concept.

CHAIR ARMSTRONG: Brian, can you answer that?

MR. NEILAN: Sure, that has definitely been in something that the TC has talked about, either at the state permitting level, at the FERC licensing level, requesting mitigation monies as part of the licensing requirements or permitting process. It's going to be on a state-by-state basis. But I think there is certainly support for requesting that during the licensing process. Any kind of mitigating monies to increase passage, or increase sampling, whether it be biological or sampling surveys. Having these hydroelectric companies contribute monies as a continuance of their permitting.

MR. BORDEN: I think that would be useful. Thank you.

MS. STARKS: If I could follow up, this is Caitlin.

CHAIR ARMSTRONG: Yes, go ahead, Caitlin.

MS. STARKS: I just wanted to note that the Technical Committee is actually working on developing a memo with some recommendations related to passage for the Board to consider in the future, and will hopefully include some recommendations as to specific things that could be addressed in a letter, such as what you suggested.

CHAIR ARMSTRONG: Lynn Fegley.

MS. FEGLEY: While we're on the topic of letters. I wanted to just circle back around to John McMurray's point, and where I started with the Northeast Fisheries Observer Program, and wondering if we as a body should be sending a letter to the Council, asking for prioritization of shad in these ocean fisheries.

CHAIR ARMSTRONG: Justin Davis.

DR. DAVIS: I appreciate you giving me a second opportunity. My question is for Pam. I was interested to see in the AP recommendations a recommendation to focus on recreational harvest and incidental catch. I'm wondering, was that motivated by discussions amongst the AP that there is a thought that recreational harvest or incidental catch might be substantial enough in some systems.

That having a better handle on it would change our perception of what is or isn't contributing to declines of this species in various systems, or was it more just that is another data gap. It's one to consider taking a look at, but there is not a thought that it's really a substantial contributing factor?

MS. LYONS GROMEN: Yes, I think it was the latter. It was recognized more as a significant data gap. In some systems we wouldn't know if recreational catch was impacting the stock, because there isn't great information. I think it was also looking at more of a coastwide, you know looking at coastwide at trying to get a better handle on recreational catch, because MRIP does a poor job of sampling for these species because of its reach. Yes, your words, a data gap.

CHAIR ARMSTRONG: I think that's all I have on the list of Board members. Toni, anymore Board members?

MS. KERNS: You do have a couple more Board members that raised their hand, and still some members of the public. You have Cheri Patterson and John Clark.

CHAIR ARMSTRONG: Okay, go ahead, Cheri Patterson.

MS. CHERI PATTERSON: I also wanted to kind of follow on with Lynn's recommendation to get ahold of the Council. But we should also put this in front of the ACCSP Bycatch and Bio Committees, to have them review that to move shad up the line for sampling, as a more critical species for the bycatch.

CHAIR ARMSTRONG: Thank you, Cheri, that's a good suggestion. John Clark.

MR. JOHN CLARK: Thank you Brian and Pam for the presentations. I want to follow up on the question that Roy Miller asked about the Delaware stock, Brian. It seems like we are putting in a lot of effort to quantifying what is going on with the mixed stock in the lower Bay there. Yet, you know just looking at Delaware and New Jersey's harvest in 2019, Delaware had about 2,400 pounds, New Jersey about 1,800 pounds, or 18,000 pounds rather.

This is a pretty minor fishery right now, and based on the comments from the Advisory Panel about that adequacy of the data we're getting on adult shad in the Delaware River. Does the TC feel that the efforts to evaluate and assess these stocks in the Delaware should be more focused on improving the surveys on the adults that are returning to spawn?

MR. NEILAN: Thanks, John, I think the focus right now is on better understanding the mixed-stock fishery. As you said, in 2019 New Jersey harvested, I think 18,000 pounds. That was our total harvest. In the mixed-stock fishery it was probably about half that. We think we need to move forward at looking to see if the juice is worth the squeeze.

If getting the correct data to figure out if reducing the fishery will have any impact at all on improving outlooks for other fisheries. But certainly, improving the power of our surveys is another priority. I think two of our main surveys just didn't quite meet it for the juveniles. As a result, weren't included in the assessment. At least within the Delaware Basin, those are the two priorities.

CHAIR ARMSTRONG: Okay, we're doing okay on time, so I would like to take a couple of public comments, if you could keep it brief and to the point, please? Toni, could you call out who.

MS. KERNS: Yes, we can do that. Jeff Kaelin and Jim Fletcher, and then after we do the public comment, Geoff White from ACCSP has a comment as well.

CHAIR ARMSTRONG: Jeff Kaelin, go ahead.

MR. JEFF KAELIN: Thank you, Mr. Chairman, members of the Board. I'm Jeff Kaelin; with Lunds Fisheries in Cape May, New Jersey, and I've been in the herring fishery since the early '80s, and we continue to operate in that fishery. Although, as everybody knows the quotas are a fraction of what they've been historically, due to recruitment problems. Likely coming from a warming ocean. One of the things that frustrated me, and looking at the information that we had before us at the AP, is there is really very, very little data that we could use to compare mortality effects, and specifically still haven't really seen any data from the bycatch avoidance network that have been in place for several years.

That data exists. I think the shad hatches and the herring midwater trawl fishery, and mackerel midwater trawl fishery are fairly low. I think the thing that is frustrating in these, we're not seeing any numbers that you can compare one against the other. In my experience for many, many years, working with the Science Center.

It was my recommendation that the Commission think about reaching out to the Observer Program at the Science Center to prioritize shad data collection going forward. There is going to be or already is an industry funded monitoring program established for the herring fishery. Of course, that quota has been reduced by 80 or 85 percent over the last couple of years.

The mackerel quota is a fraction of what it has been historically, so there is not a lot of effort in that fishery. But it's going to continue to be monitored through the IFM program that will include some kind of shoreside monitoring program that the Agency is supposed to establish, that would be used in combination with cameras on our boats.

For example, through an experimental fisheries program. There is data on shad catch in this offshore fishery that is available. But again, it's a frustration of mine, having been an AP member for many, many years that a lot of times we'll get some recommendations. But we don't have data to kind of compare the mortality effects of the various fisheries that may be affecting the shad stocks.

I just wanted to make that comment, and hopefully we can dig a little deeper for the next assessment, and look at some real numbers rather than perhaps just using the shorthand that, well, the offshore intercept fishery could be the smoking gun. I really don't think the data supports that, so I just encourage an evaluation of that existing information. We certainly would support any additional data collection that the Commission would want to see here. But again, a frustration that we're not seeing the data we already have. Thank you.

CHAIR ARMSTRONG: Thank you, Jeff, that is a good suggestion. There are data that do exist that could be summarized. It's hard, but it can be done. Toni, help me out. I can't read my own writing, to see who was the second number up there.

MS. KERNS: It was Jim Fletcher.

CHAIR ARMSTRONG: Jim Fletcher, okay go ahead, Jim.

MR. JIM FLETCHER: My question is on the otoliths to the 2 percent. Are we studying the otoliths with scanning electron microscopes? Because some countries, they are studying the otoliths of the fish with scanning electron microscopes, to get better age, but they are also discovering that they can show chemical contamination or where the fish pass through chemicals. My question is, are we using scanning electron microscopes to study the otoliths of shad, and then is it possible that we could get some report on the success of the Indian Tribes in Virginia that are using enhancement that may be able to be used in other areas? Thank you.

CHAIR ARMSTRONG: Thank you, Jim. Brian, would you like to take a crack at that?

MR. NEILAN: I'll give it a shot. As far as the microscopes that are being used. These otoliths are just being aged under low powered standard optical microscopes, just for aging purposes. Nobody is looking at scanning electron and trace elements for looking at origin. As far as the question about the Native Tribe, I don't really have any info on that.

CHAIR ARMSTRONG: All right, thank you. Back to the Board. Toni, any more hands?

MS. KERNS: Yes, you have Geoff White.

CHAIR ARMSTRONG: Oh yes, Geoff White, go ahead.

MR. GEOFF WHITE: Thank you, Toni, and thank you, Mike and the Board for indulging me. I just wanted to note, I appreciate Cheri's point about the ACCSP Biological and Bycatch meetings coming up. Those are February 17 and 18, and so for your staff members participating in that and updating those matrices on priorities, we look forward to your feedback during those meetings. That's it.

CHAIR ARMSTRONG: Thank you. All right, I think we'll move to discussion. We don't necessarily need a motion, but I've heard some things that maybe we want to do a motion to reinforce some things. If I can summarize what I heard is, shad continue to be depleted, but some of the problems are the data are very poor in many of the systems.

The systems that have been judged depleted or unsustainable, in most of the cases there is not much of a fishery left. In the one that is a concern unsustainable from Delaware, they are redoing their sustainable fishery management plan, so that the TC will get a crack at evaluating that. A lot of the concerns are about the data and data inadequacies, and about habitat problems, including passage.

I'll remind everyone that every state sent in a response to three questions that have risen about the assessment, identifying areas of concern of the assessment. Identifying additional information that could provide more context to the assessment, and suggesting management or monitoring changes or restoration that would improve shad stocks, and every state provided a response to those. I'll open the floor to discussion or possibly motions.

I do, not to be heavy handed, but what I heard, and I don't know if we need a motion or not. We may want a letter to FERC or U.S. Fish and Wildlife regarding passage. We may want a letter to NMFS or the Councils, prioritizing bycatch. Let's see, we may want to charge the ASMFC Bycatch Committee to raise the prioritization of shad on their list. We may just do a general one, saying we recommend that all states address the TCs concern to the practicable. Then Brian, there was one, the TC asked us to do, which was charge them to develop methods to evaluate bycatch, and jump in, Brian. I think that was the tone of what was being asked. Anyway, that is what I heard, so I'll open the floor. Any discussion?

MS. KERNS: You have Joe Cimino from the Board and then one member of the public.

CHAIR ARMSTRONG: Go ahead, Joe.

MR. CIMINO: I was remiss in my first time at the microphone, not to thank the AP and the TC for the thorough work and review that they did there, and the great presentation by Brian and Pam, it is much appreciated. You did lay out a lot for us, and I would be interested in a discussion on something that Jeff Kaelin brought up too.

Not just to prioritize bycatch sampling and observer sampling, but to also prioritize collecting and analyzing the data that already exists. As a Council member, I tend to take that up with the Council as well. I would like to put a motion out there, because I think it's pretty simple. The TC has done a lot of work, but they are asking to do a little more.

I believe staff has the motion already written on that**. I would move to task the Technical Committee with developing methods to evaluate bycatch removals in directed mixed-stock fisheries in state waters in order to understand and reduce impacts to stocks outside the area where directed catch occurs.**

CHAIR ARMSTRONG: Okay, do we have a second of that motion?

MS. KERNS: Justin Davis.

CHAIR ARMSTRONG: Seconded by Dr. Davis. Go ahead, Joe.

MR. CIMINO: I don't need to spend a lot of time on this, since it was a TC "ask," and I think as I said, Brian did a great job presenting this, and Caitlin also, who has gone back to this several times.

CHAIR ARMSTRONG: Okay, any discussion, Board members?

MS. KERNS: I don't have any Board members with their hand up.

CHAIR ARMSTRONG: You had one member of the public?

MS. KERNS: Correct.

CHAIR ARMSTRONG: I'll take that.

MS. KERNS: Des Kahn.

MR. DESMOND KAHN: Thank you, Mr. Chairman. I would like to point out, and I have not had a chance to fully read the assessment yet. I apologize for that. I worked on the 2011 sustainability evaluation for the shad stock in the Delaware River, and during the course of that I had been aware from work on the Connecticut River that there was peer reviewed published research that clearly showed that the large build up in striped bass since say the early '90s, was associated with a steep decline in both the American shad and the blueback herring runs up the Connecticut River.

That research was supplemented by work conducted by actually Justin Davis on, I believe his PHD research, where a large-scale diet study was conducted on striped bass in the Connecticut River, and in the spring, I think they looked at, or they estimated roughly 100,000 bass in the Connecticut River in the spring, and they are not spawning.

What they are doing is eating, or what they were doing at that time is eating shad and herring, as the diet study made clear. I decided to take a look at the Delaware, and see if there was any evidence of something like that going on. I plotted the index of abundance of striped bass in the waters of the state of Delaware with the index of abundance of the shad run, well up in the Delaware River.

My jaw hit the floor! It was like a mirror image. There was a very significant negative correlation. When bass were in very low abundance in the ’80s, the shad run in the Delaware River was booming. When bass started to increase in the ’90s, the shad run in the Delaware declined. When bass were at their peak in 2000, the shad run was at a very low level in the Delaware.

Since then, when we’ve seen some small decline in the bass stock, you know the shad run has responded. It’s very clear to me that there is a predation impact, and when you built up the stock of a predator like striped bass, which is as Dr. Victor Crecco pointed out years ago, striped bass is the only marine predator that can follow fish like river herring into fresh water, and shad also.

I just would like to point out that you know looking at bycatch, which we’ve just heard from Mr. Kaelin the midwater trawl fishery for Atlantic herring and mackerel have declined significantly. I think you’re looking up the wrong tree there. If the Commission would come to grips, and do a serious study of the impact of striped bass on alosines, I think you would be really looking at what really seems to be controlling their abundance. Thank you very much.

CHAIR ARMSTRONG: Thank you, Des, interesting topic to ponder. We look forward to your publication on it. Back to the Board, any further discussion? Any hands, Toni?

MS. KERNS: I don’t have any other hands raised.

CHAIR ARMSTRONG: All right, I’ll call the question. I will go out on a limb and say, I think we can do this without a roll call. Are there any objections to this motion?

MS. KERNS: I see no hands raised in objection.

CHAIR ARMSTRONG: Okay, well, do we have to.

MS. KERNS: I think I just need you to say motion carries without objection.

CHAIR ARMSTRONG: The motion carries unanimously. All right, further discussion, considering a management response to the benchmark assessment, or motions.

MS. KERNS: Lynn Fegley.

CHAIR ARMSTRONG: Go ahead, Lynn.

MS. FEGLEY: With all respect to Des’s comment, which is pretty interesting. I’ll just put it out there, we do need a motion to communicate with the Council about prioritization of bycatch, and also to let the ACCSP move the shad up in its priority matrices. If we need a motion, I would make one. But if we can just do that by consent, so be it.

CHAIR ARMSTONG: Caitlin, what do you think?

MS. STARKS: Well, I’m actually going to defer to Toni on whether we need a motion on this one or not.

CHAIR ARMSTRONG: Okay.

MS. KERNS: I guess, Lynn, I just have a question to you. The NEFOP is clear to me letter to Northeast Fisheries Science Center and GARFO. But for the ACCSP, are you looking for a letter, or are you all just agreeing as a Board that you will ask the staff that are attending that meeting to increase the prioritization level for shad at the meeting?

MS. FEGLEY: Yes, I think that is probably right. I think the latter, the ACCSP part we can probably handle internally with our staff. But it's the Council part that I think is more important.

MS. KERNS: Just so I'm clear, you're looking for a letter to go, who do you want the letter to go to outside of GARFO and the Science Center? Do you want it to go to the Councils as well?

MS. FEGLEY: Well, I guess I'm not entirely sure. I would imagine it would be to the Mid-Atlantic and the New England Council. I'm sure there is somebody better than I on that.

MS. KERNS: You have Megan Ware with her hand up.

CHAIR ARMSTRONG: Megan, go ahead.

MS. MEGAN WARE: I'm thinking that the Science Center and GARFO might be the most appropriate recipients to that letter. I'm just speaking up for the New England Council. There is not a shad fishery management plan for the New England Council. That recipient feels a little off to me. But if others disagree, please let me know.

MS. KERNS: You have a couple hands that have gone up since then, Mr. Chairman. I will read them slowly. We have Cheri Patterson, Max Appelman, and then you do have a member of the public, Jeff Kaelin who put his hand up.

CHAIR ARMSTRONG: Go ahead, Cheri Patterson.

MS. PATTERSON: I agree with Megan. I'm not quite sure the benefit of including the New England Fishery Management Council in the letter, but definitely NOAA Fisheries. I would make suer that they understand that we're concerned about mixed-stock fisheries, and appropriate sampling for shad.

As for ACCSP, I would recommend everybody on this Board to know who their Bycatch and Bio personnel are that go to ACCSP meetings, or it might be one now, I'm not sure. Just recommend that they have this conversation, in regards to shad sampling, because this would also elicit some new proposals for funding through the ACCSP program, to help with this concern.

CHAIR ARMSTRONG: Max Appelman.

MR. MAX APPELMAN: Hi Mr. Chair, thank you. Yes, so not opposed to sending a letter, but given the, I recognize that there is no formal motion up on the table right now. But recognizing the conversation here, and the content of what that letter would be, and who it would be written to. I would just want to make it clear that I would be abstaining if there was a motion to this effect. But again, not opposed to the letter. We certainly welcome any input, and would look forward to working with the Commission on these issues.

CHAIR ARMSTRONG: Thanks, Max. I'm going to hold off on public comment right now, we're dropping a little behind schedule. What I hear is we don't need a motion to charge ACCSP with prioritization, but we probably do, to do a letter. Toni, is that right, to do a letter to NMFS? Do you think it would be cleaner to have a motion?

MS. KERNS: Mr. Chair, I'm hoping you can hear me, because my computer is telling me I'm experiencing network connection problems.

CHAIR ARMSTRONG: I do hear you.

MS. KERNS: Okay, perfect. I just wanted to know who Lynn wanted to send the letter to. If there is unanimous consent amongst the Board, noting that NOAA Fisheries is abstaining, we can bring that recommendation to the Policy Board, and you don't have to write. We don't have to have a specific motion; we'll get something for you to bring to the Policy Board this afternoon. But Justin Davis does have his hand up, and I notice that now, we would send that letter to the Science Center and GARFO.

CHAIR ARMSTRONG: Justin Davis.

DR. DAVIS: I just wanted to make a general comment, if that's okay. It's not related to the letter, if that is all right at this point. I wanted to acknowledge the comments that Des Kahn made, I think making some really good points. My impression is that the issue of predation, and then what role it might be playing in shad and river herring, both the declines we experienced over the last 20 years, and then continued low production.

It's a difficult thing, I think for this Board to address, because it really gets to that ecosystem management problem. I think there might be a sense of sort of well, what can the Shad or the River Herring Board do to try to address an issue, where other animals out there in the ecosystem are potentially exerting this predatory pressure on these species.

What I think it just points to is that when we have deliberations on the Striped Bass Board, for instance, coming up over the next couple years on Amendment 7. We had some discussion at the Striped Bass Board this week about whether or not it was appropriate to sort of indicate to the public that the reference points that are currently in place might be unattainable, that they might be unreasonable.

I think we also need to sort of make it clear to the public that there are inherent tradeoffs there. That if we want to have a really abundance striped bass stock, that the tradeoff there is we may not then also be able to have abundant shad and river herring runs in some areas, because those fish are going to exert a lot of predatory pressure.

I think it just means we need to keep that in mind when we're talking about striped bass management, and management of some of these other predatory fish, that there is a tradeoff there that can negatively impact these fish. I just wanted to acknowledge Des' comments. I think they are good, and they are something that we need to keep in mind.

CHAIR ARMSTRONG: Thank you, Justin. I guess I'll just ask, and we'll try to do this by consensus. Are there any objections to asking staff to ask ACCSP to increase the priority of shad, and to write a letter to the appropriate people at NMFS, to ask for more bycatch sampling? Are there any objections to that?

MS. KERNS: No hands.

CHAIR ARMSTRONG: No hands, thank you, any null, and I believe we probably have one abstained, is that right, Max?

MS. KERNS: That's correct, Mr. Chair.

MR. APPELMAN: That's correct.

CHAIR ARMSTRONG: Okay, motion passes very unanimously with one abstained, however you want to say that. All right, is there more discussion or more motions to be made? I do believe there is one. Brian, I believe the TC asked us to charge them with developing some bycatch methods.

MR. NEILAN: Yes, I think Joe's motion captured that.

CHAIR ARMSTRONG: Yes, you're right. It's staring me right in the face. Thank you. Any further discussion on Item 4?

MS. KERNS: No additional hands are raised.

REVIEW TECHNICAL COMMITTEE RECOMMENDATIONS ON IMPROVEMENTS TO AMENDMENTS 2 AND 3

CHAIR ARMSTRONG: All right, then I think we'll move on to Item 5, which is to Review the Technical Committee Recommendations on Improvements to Amendments 2 and 3. Brian, you have a presentation on this.

MR. NEILAN: Yes. Again, my name is Brian Neilan from New Jersey, I'm the TC Chair on the TC. This presentation here will be Technical Committee recommendations on a recent Board task, specifically improvements to Amendments 2 and 3. Here is a quick run through of what this presentation will be touching on.

First, a little background on what the Board task was, and the TCs recommendations based on this task. Finally, the actions that the Board will need to consider. A little background. This task goes back to 2017, when the TC identified some inconsistencies between state management programs and the shad and river herring FMP.

Just for reference, Amendment 2 is River Herring Management, and Amendment 3 is Shad. In the fall of 2019, the TC presented a report on state inconsistencies, and recommendations for resolving each issue. This past summer the Board approved the state proposals to resolve any of these inconsistencies between the state plans and the coastwide FMP.

This is the current TC task we'll be working through today. After the states resolved the inconsistencies in their plans, the Board tasked the TC with developing improvements to Amendments 2 and 3, with regards to the following items. First, management and monitoring of rivers with low abundance and harvest of shad and river herring.

A standardization of sustainable fishery management plan requirements, in regards to contents of the plans. Metrics used for benchmarks, and management responses to the benchmark is triggered. Incorporation of stock assessment information into SFMPs, and their discussion on the timeline for renewing these plans.

Some clarification on de minimis requirements as they retain the SFMPs, and review at a number of years of data that are required before developing a metric for an SFMP. That is the task. Looking at Number 1, Management and Monitoring. Rivers with low abundance in harvest of shad and river herring.

The TC does not recommend any changes to the FMP to address commercial fisheries. Commercial fisheries will still require a standard SFMP, with commercial reporting, biological sampling, et cetera. The TC does recommend that the SFMP should clarify the management of recreational fisheries, that they should be dependent on the availability of harvest and monitoring information. Under Amendments 2 and 3 to the FMP, states may implement with Board approval, alternative management plans. We are referring to them as AMPs, for river herring and shad that differ from those required under the FMP. They must demonstrate that the proposed management program will not contribute to overfishing of the resource, or inhibit restoration of the resource.

The TC recommends that the above chart be used to determine when each type of management plan is appropriate, whether it be a standard SFMP, an alternative management plan, or if the states should be required to implement catch and release only regulations. This chart would be applied on a state by state or a system-by-system basis.

Just to reiterate, this would be applied to your recreational fisheries only. Looking at this chart that Caitlin developed. On the left there are the categories of recreational harvest, including known or suspected harvest, unknown recreational harvest, but concerned species presence, and no recreational harvest, and it's generally accepted that the species is absent from the system, or the systems outside the species generally accepted range.

Then on top there we have the categories of data to support a management plan, whether it would be sufficient fishery dependent or independent data, or insufficient data. Just to run through this chart here. If you have known or suspected recreational harvest of shad or river herring, using this chart you would be required to develop and improve SFMP, with appropriate sustainability metrics, monitoring and management responses.

Otherwise, you would implement catch and release only recommendations, if you didn't come up with an SFMP. For these purposes, known harvest is that which is recorded in official surveys or reports, where suspected harvest is identified through anecdotal information from fishermen, or historical information in systems that don't have an official monitoring of recreational harvest.

The TC would be responsible for determining whether monitoring data are sufficient, or insufficient for proposed uses. For systems with known populations of river herring and shad, but no known suspected recreational harvest, the state or jurisdiction using this chart would have the ability to either close or implement catch and release only regulations, allow recreational harvest under a Board approved SFMP, with the appropriate sustainability metrics.

Responses or 3, allow recreational harvest under Board approved alternative management plan. Any recreational harvest is confirmed through official avenues, at which point the state would be required to develop a standard SFMP. Using an alternative management plan would not require sustainability metrics. For systems with known small populations of river herring, shad, and no suspected harvest, but without system-specific monitoring.

The state would either close or implement catch and release only regulations, allow harvest under a Board approved SFMP with appropriate sustainability metrics, or again, allow recreational harvest under an AMP, until recreational harvest is confirmed. Finally, for systems with no known populations of river herring, and consequently no suspected harvest, and no fishery independent data. The state or jurisdiction would either close or implement catch and release only regulations, or allow recreational harvest under a Board approved AMP. If river herring or shad were to become present, the state must resubmit a proposal to the TC for an SFMP. If you have insufficient data and unknown harvest, or known harvest, and the species is known to be present. You would have to default to catch and release only under the use of this chart. This is how this chart would be applied for considering SFMPs, alternative management plan, or catch and release only regulations.

Standardization of SFMP requirements, in regards to metrics and management responses to triggers. The TC did not recommend additional requirements for the type of sustainability metrics that can be used in the SFMPs. The TC does recommend additional language be added to the FMP, to strengthen or clarify whether system-specific or state-specific plans in the following areas.

First, the level of detail required in the plans or management response to the stock falling below defined sustainability target or threshold. When a state may relax restrictions implemented in response to falling below the sustainability target or threshold, and management of interjurisdictional water bodies.

In regards to management responses, Amendment 2 states that if stock is below optimum level, the management plan must detail restrictions that will be enacted to allow for increase in spawning stock abundance and juvenile recruitment. In regards to Amendment 3 in shad, it includes wording that said "discussion of management measures to be taken if sustainable target is not achieved within an indicated timeframe."

The TC recommends adding the following language to the FMP to clarify the language that details the type of restrictions that can be considered, allowing a plan to provide multiple options for restrictions. Basically, one option is a tiered approach to severity of response based on how far below a threshold is triggered.

The TC also recommends adding language requiring that a state must notify the Board in the next Annual Compliance Report if the stock falls below an SFMP threshold, and pursue implementation of the management response for the following calendar year. In regards to relaxing management restrictions, Amendments 2 and 3 say proposals to reopen closed fisheries may be submitted in the annual compliance report, and will be reviewed by the PDT, the TC, as well as the management board.

This one, the TC recommends adding specific language to clarify when a relaxing of the restrictions may be considered for approval. Specifically, if a state has implemented a management restriction in response to the stock falling below sustainability targets, the management restrictions must stay in place until the sustainability targets have been met for at least five consecutive years.

For 2C, in regards to interjurisdictional management guidance. Amendment 2 encourages cooperative development of SFMP targets. Amendment 3 seems to say both agencies should have plans, unless there is a cooperative involved. The TC recommends the following, cooperative development of one shared SFMP for the entire system. This would include consistent targets and metrics, and when possible, consistent management measures for fisheries permitted by jurisdictions in shared water bodies, similar to regional management approaches that are done in other ASMFC managed fisheries. For Item Number 3 for this Board task, incorporation of stock assessment information into SFMPs, and discussion of timeline for revealing plans.

There is concern among TC members that for many systems there is inconsistency between the information used to assess stock status through the stock assessment, and those used to develop sustainability metrics for the SFMPs. For example, some data sources are being used for benchmark development in SFMPs, but didn't meet the time series or power requirements used in the stock assessment or the benchmarks, and used in SFMPs are saying on thing about stock health. Then the assessment had a conflicting finding.

For these issues, the TC recommends compiling information on current monitoring programs by species and systems, and developing recommendations for improvements for use in SFMPs and assessments. Additionally, the TC recommends no change to the five-year timeline for renewing SFMPs and AMPs.

Issue 4 is in regards to clarification of de minimis requirements as they pertain to SFMPs. The current definition under Amendment 2 and 3 states, that states that report commercial landings of river herring or shad that are less than 1 percent of the coastwide commercial total, are exempted from subsampling informational and recreational catch for biological data.

This does not exempt states from the requirement to prohibit recreational harvest and possession, unless they have a Board approved management plan. This is a quick one that the TC does not recommend any changes to the current de minimis requirement, and an exemption for states with de minimis status.

The last issue, Issue Number 5 is in regards to the number of years of data required before developing a metric for an SFMP. As it sits now, Amendments 2 and 3 do not contain explicit requirements for timeseries length. After some discussion the TC recommended the minimum of 10 years of data required to establish a primary sustainability metric, through an SFMP or an AMP, for both shad and river herring.

With one caveat for river herring, river herring's shorter time series in the 7-to-9-year range would be considered by the TC on a case-by-case basis, if the state can provide additional information to justify the shorter time series. You know any sort of examples, exploitation rates, stock size, whatever they think can justify the use of a shorter time series.

One example of a shorter time series being used is in Maine. Last year they only had seven years of run counts of river herring, but the runs were strong, continually increasing, and they had very low proposed exploitation rate, and a high stock size target, so the TC felt given that information that they could go ahead with the shorter timeseries. That is the TCs recommendation for the original Board task.

In hashing out the recommendations for this Board task, the TC developed some additional recommendations beyond what was originally tasked by the Board. The TC felt that there is quite a bit of gray area, in regards to the use of AMPs, and recommends the following requirements if the states intend to develop an alternative management plan. The first recommendation is that the AMP will include a rationale or justification for why a standard SFMP cannot be used. That a justification that the proposed management program will be conservationally equivalent to catch and release only regulations.

An explanation of how the state will determine if and when the AMP is no longer appropriate. The data source to risk and monitoring, and sort of potential catch or harvest. Any triggers for when you will switch from an AMP to a standard SFMP, and a description of a management response the triggers met.

One example, if a harvest is documented through a creel survey for three consecutive years, catch and release only regulations will be implemented state wide for the first specified systems, unless or until a standard SFMP is developed. Finally, if a management trigger in an AMP is met, the state must notify the Board in the next annual compliance report, and pursue implementation of a management response to that trigger in the following calendar year.

A few more additional recommendations. Another issue the TC discussed was the idea of allowing limited recreational harvest in systems with an SFMP or AMP using a low state wide bag limit. The TC does not recommend allowing any recreational harvest to occur on systems that are not managed through either an approved SFMP or an AMP. Unmonitored systems could experience unchecked recreational fishing pressure if this were the case, which would be detrimental to the small stocks.

Finally, the TC does recommend AMPs allowing statewide recreational bag limits or no recreational regulations must include a trigger to implement catch and release only regulations, or propose an SFMP. That was everything the TCs recommended on the Board task for the Board to consider. I think Caitlin is going to take over from here. Staff will be able to better describe the steps going forward for Board consideration.

MS. STARKS: These are a couple of different routes that the Board could consider, in response to these Technical Committee recommendations that Brian has gone over. The first is to consider initiating a management action, which I think would be an addendum to modify the FMP, according to the recommendations that the Technical Committee has made, where they have recommended adding language or clarifying certain portions of the FMP.

Then just as a note, I kind of put some tradeoffs with these two different options. The second option that I see as a path forward is to task the Technical Committee with developing a Technical Guidance Document that includes all these recommendations, and that would guide their development and evaluation of sustainable fishery management plans, or alternative management plans going forward.

The first route is, you know possibly more time and resources to do an addendum. It does possibly give the Board more enforceability of the requirements that are being recommended, since they would be written into the FMP. The second route may take a little less time. It would only involve the Technical Committee developing this guidance document. But it goes with less enforceability of those recommendations, it wouldn't actually be requirements written into the FMP. I just wanted to lay those out as some potential next steps for the Board, and I think that is all we have for this presentation.

CHAIR ARMSTRONG: All right, thank you, Caitlin. That is a lot of material to digest, and it's clear that Amendment 2 and 3 had some problems that need to be addressed. The question is, which route do we want to go? Do we want to do an addendum, or do we want to task the TC with developing a guidance document when evaluating sustainable fishery plans or alternative plans? Discussion, anybody have an opinion which way to go?

MS. KERNS: Mr. Chairman, you have Justin Davis, and David Borden.

CHAIR ARMSTRONG: Go ahead, Justin Davis.

DR. DAVIS: I guess I'll start off by thanking the TC for this tremendous amount of work. It always impresses me with this Board, and the technical work that goes on, TC tasks and stock assessments, just how much information there is to deal with and handle, because rather than sort of just having one coastal stock, we've essentially got this patchwork of stocks, multiple stocks within each state up and down the coast, all with their own little ins and outs, and differing levels of available data and considerations.

This is a tremendous amount of work, and I really appreciate it. You know I guess my feeling, after looking at this, is that I would sort of prefer Option Number 2 here. I think it's great that we've made some effort to, and given some attention to potential inconsistencies between the two amendments, how we're managing the two species groups.

My impression of how the management program, prescribed by these amendments have been working since they've been put in place, is that there has been a nice balance between striving towards meeting all the requirements laid out by the FMP, and providing good data sources to help improve management.

While at the same time allowing some flexibility for states, because of those unique considerations and little ins and outs that I mentioned. I guess I prefer Option 2 here, to sort of maintain that kind of status quo or paradigm, you know with the idea that if we have a technical guidance document, that can certainly help the TC in guiding states in developing these plans and improving them, without potentially going through the time and effort of doing an addendum to the FMP, and working through all this in detail.

It seems to me like the TC has a good handle on the improvements that can be made, and by just developing a technical guidance document and letting them use that to guide them in evaluating these plans, that would be the best way forward. I would be willing to make a motion to that effect, if you're ready for that at this point, Mr. Chairman. But I'll also defer if you would like there to be an opportunity for more discussion.

CHAIR ARMSTRONG: Yes, Justin, let's hold off just a little bit, and I can get a couple more comments, and see if we're all heading in the same direction, if it's all right with you. David Borden. We can't hear you, David.

MS. KERNS: David, you are unmuted. We just can't hear you. Mr. Chairman, I don't know if while David is working out his sound problems, Doug Haymans also has his hand up.

CHAIR ARMSTRONG: Go ahead, Doug.

MR. DOUG HAYMANS: Thank you, Mr. Chairman, it's rare that I hear Toni call my name two times in a row like that. I would agree with Justin's comments, and would prefer that we look at Number 2 there. As a state with limited to no fisheries, especially in the river herring category.

I would prefer to be able to work within the ASFMC process, our Technical Committee representatives, and pleased with the direction the Technical Committee is working in right now. I would like to keep it that way, so my preference would be in agreeing with Justin, and I would support with a second his motion, when the time is appropriate.

CHAIR ARMSTRONG: Thank you, Doug, anymore comments? Toni.

MS. KERNS: I don't have anybody else's hand up. Cheri Patterson. Hold on, okay. I have Cheri Patterson, Chris Batsavage, and Roy Miller.

CHAIR ARMSTRONG: Okay, go ahead, Cheri.

MS. PATTERSON: I'm a little torn here. I understand that the technical guidance document would definitely require less time, but here is the problem I have, is it provides less enforceability of requirements. I think that it is important to note that we have these FMPs in place, in order to make sure that states are monitoring appropriately and consistently.

I'm not sure that that is occurring on a consistent basis. Just doing a technical guidance may not help with that sort of concern. I'm torn. I have a tendency to lean towards moving forward with an addendum, in order to correct anything in the current FMPs, as recommended by the TC, so that there is no question within the TC when they do these marvelous reviews, as to what is required for them to review and management actions.

CHAIR ARMSTRONG: Thank you, Cheri, Chris Batsavage.

MR. CHRIS BATSAVAGE: I share many of the thoughts and comments that Cheri just made about which way to go. I'm also torn. I'm leaning more towards the addendum route. A question I have is, the recommendations given by the Technical Committee for clarifying these issues in Amendments 2 and 3. Would those invalidate any of the AMPs that are currently in place? Based on that I may have a follow up.

MS. STARKS: I think I can answer that, Mr. Chair. Chris, I don't believe that any of the current AMPs would go against the recommendations of the Technical Committee, and I think the Technical Committee had those in mind as they were developing these, as those alternative plans were being developed this past year, figuring out the best way to put those together. I think those are part of what the recommendations include. I don't think it would invalidate them.

MR. BATSAVAGE: Thank you for that, Caitlin. That is helpful, as far as helping me decide which side of the fence to lean on. I'm leaning more towards the addendum side at this point.

CHAIR ARMSTRONG: Roy Miller.

MR. MILLER: I think I'm leaning more with Chris and Cheri on this. If I could make a suggestion. If we decide to task the TC with developing a technical guidance document, then I would urge that this document be reviewed at regular intervals. Certainly, at every stock assessment update.

But if that is five years, then maybe we should review the performance in meeting and recommendations of the technical guidance document at three-year intervals, or something like that. I'm concerned about producing a report and then just having it sit on the shelf and gather dust.

CHAIR ARMSTRONG: We have Allison Colden.

DR. ALLISON COLDEN: Not to simply pile on here, but I'm sort of on the same line of thinking as the last few speakers, with regard to the greater enforceability of an addendum over a technical guidance document. The one thing that struck me from today's presentation was, you know the timeline of this discussion. These issues are first inconsistencies, the first identified in 2017.

You know we took action to address those inconsistencies in 2019, and this seems to me like the next logical step to sort of codify the changes that the states have already made, as well as the guidance that we've gotten today from the Technical Committee moving forward. I'm comforted by the answer to the previous question, as to whether or not this would immediately impact any of the existing SFMPs. I am also leaning in support of an addendum.

CHAIR ARMSTRONG: Any further discussion?

MS. KERNS: Lynn Fegley had her hand up before, but maybe Allison covered what she wanted to talk about, and then Megan Ware has her hand up.

CHAIR ARMSTRONG: I'll assume Lynn's okay, Megan, go ahead.

MS. WARE: I think this is a question for Caitlin, and just looking through the memo. It seems like some of the changes recommended are specific language changes in the FMP. Then some of them are more TC recommendations, or TC tasks. For example, Number 3 about the stock assessment information. I'm just trying to get a better sense of how something like Number 3 would be in an addendum, or maybe it wouldn't be.

MS. STARKS: I think with Number 3, I think you're referring to incorporating the stock assessment results into the requirements of an SFMP. I think that those could be taken out as options, if that makes sense. It could be an option to require the SFMPs to include the stock assessments metrics versus sustainability in the

SFMP, or an option to incorporate the information, but not make it a requirement that they be used as the sustainability metric set, each system is being evaluated again, if that makes sense.

CHAIR ARMSTRONG: Any further hands, Toni?

MS. KERNS: No other Board members, one member of the public.

CHAIR ARMSTRONG: I'm not going to take public comment until we have a motion to vote on. I'll go back to Justin. After hearing what you've heard, would you like to make a motion?

DR. DAVIS: Sure, I'll make a motion, just to get something up on the board to help focus discussion. I believe staff has that motion. **I move to task the Technical Committee with developing a technical guidance document to guide SFMP/AMP development and evaluation based on the recommendations presented today.**

MS. KERNS: You have a second by Doug Haymans.

CHAIR ARMSTRONG: Yes, we heard Doug. Discussion. I think you know there is clearly some people that are leaning towards addendum. I think, and I turn to Toni to step in if not. I think we just discuss this. We go ahead with a vote, and vote it up or down. If it goes down, we move to a new motion for an addendum. I think that is cleaner than trying to wordsmith this into something we can live with. Anyway, discussion on this motion. Justin, did you want to say anything else?

MS. KERNS: You have Cheri Patterson and Lynn Fegley.

CHAIR ARMSTRONG: Okay, before that Justin or Doug, do you want to say anything further?

DR. DAVIS: I guess I put the cart in front of the horse a little bit, by laying out my rationale for the motion before I actually made it. I won't add much further, other than to say I think there are arguments on both sides for doing it either way. I guess I'm just kind of thinking of the end result of either path, you know what it's going to mean for the overall management program.

I don't view the current situation as sort of being really deficient, that a lot of states are not doing things they should do. I think in some instance's states, for good reasons, are potentially asking for leeway or exceptions, but also putting effort into producing data that is helping in the management of these species.

I guess I just feel like looking at the slate of issues outlined in the memo that the TC put together, some of them don't seem like they need to be addressed through addendum. Some of them seem like if we initiated an addendum, it might put some states ultimately in a tough spot, where they might feel like they have to make a choice between complying with certain requirements that are not likely to substantially kind of add to the overall data picture for the species, or discontinuing their fisheries, given a lot of us are under resource limitations these days, and don't know how much we can devote to certain things. That is why I'm making this motion. I can see the argument on both sides, and I guess I'll just leave it at that.

CHAIR ARMSTRONG: Doug, anything further from you?

MR. HAYMANS: No sir, thank you. I absolutely agree with Justin's rationale there. We are one of those states that would be put in a hard spot if we had a mandated change for a fishery in some of our smaller rivers that are virtually nonexistent. But I agree with Justin's rationale and I continue my support.

CHAIR ARMSTRONG: Cheri Patterson.

MS. PATTERSON: I will be opposing this motion. I think the TCs recommendation is to go with an addendum. They're the ones that spend an inordinate amount of time to evaluate the FMP, and all of the conditions that they have to assess. I think it's only fair to go to the addendum process, and give them the guidance as to how to perform their work.

CHAIR ARMSTRONG: Lynn Fegley.

MS. FEGLEY: I pass, Mr. Chair, thank you.

CHAIR ARMSTRONG: All right, thank you. Further comment?

MS. KERNS: Erika Burgess.

CHAIR ARMSTRONG: Erika Burgess, please.

MS. ERIKA BURGESS: I just wanted to speak on behalf of the state of Florida in support of the comments made by Davis and Doug, thank you.

CHAIR ARMSTRONG: I'm going to do something a little unusual, but because I have such respect for science, I'm going to ask Brian if he thinks the TC has an overwhelming opinion on if we should go with this. Brian, not to put you on the spot, but I'll put you on the spot.

MR. NEILAN: No worries, Mr. Chair. I don't believe the TC has a general consensus for one or the other here. If you ask ten TC members, you would get ten different opinions. I think Caitlin did a good job of laying out the pros and cons. Initiating a management action to modify the FMP, with an addendum that will certainly make our job more easier when we're reviewing plans.

The requirements are more explicit, it's just a matter of did they check off their boxes or not. The second option here with tasking the TC with developing the guidance document, is more in line with how shad and river herring have been managed in the past, especially with AMPs. The recommendations from the TC here would kind of help shore up the AMP requirements a little better, make it a little more explicit. Unfortunately, I don't have one or the other for you. I don't know if Caitlin has anything else to add, but that's generally how I perceive the TCs opinion at this point.

CHAIR ARMSTRONG: Thank you, Brian, I think the Board is of the same mind. Further discussion.

MS. KERNS: You do not have any, Lynn Fegley has her hand up, and then you have two members of the public.

CHAIR ARMSTRONG: Okay, go ahead, Lynn.

MS. FEGLEY: I'm really pretty conflicted on this one, as you can probably tell by the fact that I keep putting my hand up and taking it down. What I wonder, we are one of those states where I have concerns about resources that could be demanded, based on requirements written within an addendum. I do have concerns about that. We got updated as the sustainable fishery management plans do at the end of the year.

But in thinking it through, I do think that there is some benefit to initiating an addendum. At that point, I think once it is in writing and we see, we can have a discussion at the Board when the draft comes before us. If there are states that feel as though they are going to get caught in a jam with resources, that maybe we can have a discussion when we see the draft. That is sort of where I'm falling down, I'll agree to support an addendum.

CHAIR ARMSTRONG: I'll take a couple of very brief comments from the public, but they need to be directed to this motion. Do you have some hands up, Toni?

MS. KERNS: We have Wilson Laney and then Des Kahn.

CHAIR ARMSTRONG: Go ahead, Wilson Laney.

DR. WILSON LANEY: As a member of the public, but also a longtime member of the Shad and River Herring Technical Committee, I would certainly, definitely lean towards the development of an addendum, and I think Ms. Fegley's comment about the fact that you all could take a strong look at it once it was drafted, and then have a further discussion about how it would impact the states, would certainly be a good way to go, because that preserves your compliance authority.

But also, it gives you the option of a drop back to a technical guidance document, if you thought that was appropriate. Just a couple of comments. I think, should the Board pass this motion, the public perception, at least from my perspective, would not be all that great for several reasons. One is the colleagues of mine Hall et al in New England and other folks, who have taken a look at the potential increase in biomass of these species, shad and river herring, with appropriate management measures in place is huge.

Secondly, Dr. Kahn pointed out to you earlier, in a somewhat backwards sort of way, the importance of these species, this whole species complex for predators like striped bass, and not only striped bass, but I think bluefish, weakfish, and other predators in the ocean like bluefin tuna, and many other species that consume shad and river herring. I think from an ecosystem management perspective, you would be better served by an addendum as well, because that preserves your enforcement authority as Ms. Patterson and Ms. Fegley have noted.

I would certainly, as a member of the public, support that approach initially, and then possibly again, as Lynn pointed out. You could have the discussion once the addendum is developed. I really don't think, and I'll defer to staff on this point, and certainly to Brian and Pam. But I don't think it would take a whole lot more effort to develop a draft addendum, as opposed to a draft technical guidance document.

I think most of your concerns are what it might require of the states, in terms of additional sampling. I certainly understand that. I think the ecological importance of these species far outweighs their present importance as recreational or commercial species. But the future potential for both commercial and recreational fisheries is tremendous, if they were restored.

CHAIR ARMSTRONG: Thank you, Wilson. Des Kahn, to the motion, please.

DR. KAHN: Yes, thanks for the chance to speak. Briefly, what I would like to suggest is that the measures that we have been presented with, recommended measures, to a great extent involve things like restricting recreational landings and so forth. I don't think that is going to get at the problem.

The problem is not caused by fishing, as I understand, and I don't think the assessment came to that conclusion. The problem as I see it is increased stripe bass predation, as I mentioned. But the other thing, I would recommend the Commission, instead of restricting a problem that doesn't really have any effect, which is recreational landings, for example.

The Commission would be better served by working on reducing dams, and obstacles to spawning runs, which would really be able to build up these stocks, if they had restored the spawning areas that they had originally, you know before white people got here. That would be a far more productive use, in my opinion, of the Commission's resources.

CHAIR ARMSTRONG: Back to the Board, any final discussion before we vote?

MS. KERNS: I see no additional hands.

CHAIR ARMSTSRONG: All right, I know Massachusetts needs to caucus, so we'll take a minute or two to caucus, please.

MS. KERNS: Roy Miller raised his hand, sorry he got it up right as I was saying no hands. I don't know if he was looking for caucus.

MR. MILLER: Exactly, I was looking for a caucus.

CHAIR ARMSTRONG: Okay, let's do that, take two minutes. Okay, is everyone all set?

MS. KERNS: I can't see hands.

CHAIR ARMSTRONG: No hands, so I think we're all set. How do you want to do this vote, Toni or Caitlin? Just raise hands?

MS. KERNS: Yes. Mr. Chairman, if you can just ask for in favor, against, abstain and nulls, and I'll read out the states, and Caitlin will give you a count.

CHAIR ARMSTRONG: Okay. All those in favor of this motion, please raise your hand.

MS. KERNS: I'm going to let the hands settle for a second before I start calling out states. Okay, we have Georgia, Florida, Connecticut, South Carolina, New Jersey, New York, NOAA Fisheries, Maine, Pennsylvania, and Massachusetts.

CHAIR ARMSTRONG: Hands down, please.

MS. KERNS: I can clear the hands, Mike. We are all set.

CHAIR ARMSTRONG: Those opposed to this motion, please raise your hand.

MS. KERNS: We have Fish and Wildlife Service, Virginia, Delaware, North Carolina, Maryland, New Hampshire, PRFC, and Rhode Island. I'll clear those hands.

CHAIR ARMSTRONG: All right, any null votes?

MS. KERNS: I see no nulls.

CHAIR ARMSTRONG: Any abstentions?

MS. KERNS: I see no abstentions.

CHAIR ARMSTRONG: All right, and what is the count?

MS. STARKS: I believe I have nine in favor and eight opposed, no null, no abstentions, but DC is absent.

CHAIR ARMSTRONG: The motion passes 9 to 8. All right, is there any further discussion of Item 5, Technical Committee review of Amendment 2 and 3?

MS. KERNS: No hands up.

CHAIR ARMSTRONG: All right then we'll move on. We have a scheduled break. I guess, why don't we take five for biological break, so we'll be back at 10:57?

(Whereupon a recess was taken.)

CONSIDER SHAD HABITAT PLAN UPDATES

CHAIR ARMSTRONG: Moving on to Item 7, Consideration of Shad Habitat Plan Updates from the States. This is an action item, and Brian, take it away.

TECHNICAL COMMITTEE RECOMMENDATIONS

MR. NEILAN: Thank you again to the Board for so promptly considering the TCs recommendations so far. This one should be pretty quick. The Shad Habitat Plan Updates that states have submitted so far. A little background under Amendment 3 all states and jurisdictions are required to submit habitat plans for American shad, which are meant to contain a summary of information current and historical spawning and nursery habitat, threats to those habitats, and habitat restoration programs within each state.

In February of this past year the Board agreed that these plans should be updated every five years or so like SFMPs, and asked the states to update existing plans. Originally approved in 2014, and for the states with missing plans to submit their habitat plan. In this case it was the Merrimac and the Hudson.

We got six plan updates that were evaluated by the TC, and submitted in time for this Board meeting. We got plans from Maine, New Hampshire, Maryland, North Carolina, a system-specific plan for the Savannah River, and Georgia. For Maine, this is a quick one. They are currently in the process of coming up soon, or coming up soon for relicensing of hydroelectric dams on a few rivers in their state.

They are exploring looking into incorporating fish passage or monies for mitigation, as part of the FERC relicensing. There are no significant habitat improvements since the last plan, and it was mostly updating tables, graphs, figures, just to get it up to date since the last one. For New Hampshire, they removed references to the Great Dam and its fishways, since in 2016 they were both removed.

Since it had a fishway there, technically no gain in habitat, but I think it's fair to say that a complete removal of the dam is going to be beneficial to fish migration regardless. Maryland updated their spawning and recalculated their spawning and rearing habitat estimates. They removed the, I might butcher this, Bloede Dam on the Patapsco River.

That removal was completed in 2019, and restored access to approximately 14 kilometers of potential riverine habitat. The Conowingo Dam remains the most significant barrier to the American shad migration in the state. Fish lifts operate there, but passage efficiency is poor. New requirements associated with pending relicensing of the dam should improve passage conditions, though upstream and downstream passage efficiency must be improved, not only at the Conowingo, but there is quite a few on the Susquehanna.

They've also added new information regarding water withdrawals, channelization and dredging, and competition and predation sections have been added to their habitat plan. Maryland feels the most significant threat to American shad in the state is habitat degradation associated with land use modifications in urban and suburban development.

The egg and larval stages of American shad are particularly vulnerable to these stressors. Rivers impacted by development are unlikely to host successful spawning runs, even with sufficient abundance. It's a general update for Maryland. North Carolina had a good number of updates to their plan in the habitat assessment sections they added some wording to be consistent with their SFMPs. They have formally designated all four of their strategic habitat areas in rule. They've added some new information to the threat's assessment section, to incorporate some information from the assessment.

They added new information about climate change issues, land use issues, and toxic and thermal discharge threats. Continuing with North Carolina, in regards to their habitat restoration program updates. The Milburnie Dam on the Neuse River was removed in 2017. The Corps has authorized a disposition study in 2019.

The fate of three dams is in question, pending the outcome of this study. They've also updated information on their hatchery product supplementation program, and their water quality improvement program. The Savannah River has a system-specific habitat plan. Some updates to this plan include status of the Savannah Harbor deepening, and plans to install fish passage at the New Savannah Bluff Lock and Dam, as some information on the navigation Lock at the Dam, which hasn't moved fish since 2013 has been updated and reiterated.

Additionally, efforts to control invasive predators such as flathead catfish are now linked to this plan, because they are seen as a source of mortality for shad and river herring. Georgia updated their plan as well. Some highlights include their removal of White Dam on the Middle Oconee River in 2018.

They've updated data on passage and removal efforts for invasive predators, again flatheads and blue cats, and they've also incorporated passage concerns from the stock assessment. Those are all the plans we had in time for this meeting. The Technical Committee reviewed all the plans that were submitted, and recommends that they all be approved. That would be Maine, New Hampshire, Maryland, North Carolina, the Savannah River and Georgia.

Next steps will be today, the Board considers approval of these plans, possible recommendations that their remaining states update any habitat plans that already exist, and that the Hudson and Merrimack submit new plans in time for the next Board meeting, which would be spring 2021, and the TC would evaluate those plans and proposed updates in time for that meeting. That is the Habitat Plan update.

CHAIR ARMSTRONG: Thank you, Brian, any questions for Brian?

MS. KERNS: I don't have any hands raised.

CHAIR ARMSTRONG: All right, seeing none, could I have a motion to approve the habitat plans that have been submitted so far.

MS. KERNS: You have Cheri Patterson.

CHAIR ARMSTRONG: Cheri.

MS. PATTERSON: Yes, thank you, Mr. Chair, is there a motion already crafted? **I move to approve the updated shad habitat plan submitted by Maine, New Hampshire, Maryland, North Carolina, South Carolina, and Georgia.**

CHAIR ARMSTRONG: A second please.

MS. KERNS: Doug Haymans.

CHAIR ARMSTRONG: Thank you, Doug. Any need to discuss this, Cheri?

MS. PATTERSON: No, I am following the TCs recommendation of the plans that have been submitted.

CHAIR ARMSTRONG: Further discussion on the motion.

MS. KERNS: No additional hands.

CHAIR ARMSTRONG: Then we'll move to the vote. I think we'll try to do this by consensus. Are there any objections to this motion?

MS. KERNS: I see no hands.

CHAIR ARMSTRONG: Any nulls?

MS. KERNS: No hands.

CHAIR ARMSTRONG: Abstentions?

MS. KERNS: No hands.

CHAIR ARMSTRONG: Motion passes unanimously. All right, any further discussion on this item?

CONSIDER A FISHERY MANAGEMENT PLAN REVIEW AND STATE COMPLIANCE FOR THE 2019 FISHING YEAR

CHAIR ARMSTRONG Seeing none, we'll move to Item 8, Consider a Fishery Management Plan Review and State Compliance for the 2019 Fishing Year. Caitlin.

MS. STARKS: I will quickly go through a review of the FMP Review and Compliance Reports for the 2019 fishing year. First, I'll cover the landings in 2019, then I'll go over passage, stocking efforts, protected species information, and de minimis requests, and then finally wrap up with the PRTs recommendations.

This table shows the state landings and coastwide totals for commercial shad and river herring, and this is directed landings and bycatch landings in 2019. All confidential data is excluded. For river herring the coastwide total was 3.22 million pounds, which is a 31 percent increase from 2018. For shad the total for 2019 directed commercial landings and bycatch is 273,450 pounds, and that is a 4 percent decrease from the landings in 2018.

As part of the requirements in Amendment 2 and 3, for river herring and shad passage counts are required on a few rivers in Maine, New Hampshire or Massachusetts, Rhode Island, Connecticut, Pennsylvania, Maryland and South Carolina. The coastwide total passage in 2019 at these locations was 6.5 million river herring, and 437,853 shad.

These represent a 31 decrease from 2018 for river herring, and a 32 percent decrease from 2018 for shad. During 2019, hatchery reared American shad fry were stocked in the states and rivers that are listed on the slide here. The total is just under 12 million American shad stocks, compared to the shad stock in 2018, which was 22.7 million.

That represents a decrease of 47 percent. There were a few states stocking efforts that did not occur in 2019 as opposed to previous years, and those included in Rhode Island, Virginia, North Carolina, and Georgia. For Virginia, the James River stocking efforts for shad ceased in 2018, however in 2019, they did stock 1.2 almost million river herring larvae in Harrison Lake, which is part of the James River system.

For sturgeon interactions in 2019, there were 139 interactions reported, with zero mortalities occurring in Connecticut, Potomac River, Virginia, North Carolina, South Carolina, and Georgia in the fisheries. Additionally, gill netters in New Jersey coastal waters reported 3,893 pounds of sturgeon discarded in 2019.

But information on the total number of fish and mortality is unknown. Then for Rhode Island their data for sturgeon interaction lags one year behind. We don't have numbers for 2019 at this point, but we do have 2018 numbers, and in 2018 they had 87 interactions reported. De minimis requests were submitted by Maine, New Hampshire, and Massachusetts and Florida for their shad fisheries, and New Hampshire and Florida also request de minimis for river herring.

Based on their commercial landings, they all meet the requirements and they qualify for de minimis status. Now I'll go over the PRTs report. After reviewing the annual compliance reports, the PRT highlighted a few items for the Board to consider. The first is just to remind the Board that in 2019 there were a few states that had allowed recreational fisheries, but hadn't implemented sustainable fishery management plans as required by Amendments 2 and 3.

However, these issues were resolved in August, 2020, when the Board approved new plans for Maine, South Carolina, Georgia, and Florida. Then other issues the PRT noted were that several states didn't report on all monitoring requirements that are listed under Amendments 2 and 3. The FMP review does provide a table of all of these issues by state.

But it's noted that a couple of states have been consistently missing some information for a few years, and the most common emissions are the characterization of other losses, characterization of recreational harvest, length and age frequency, and degree of repeat spawning. The PRT recommends that these states take a look at that table and take note of those required monitoring programs that were not reported on, and make sure to include those in their future compliance reports.

Additionally, most states did not submit their monitoring data in a separate Excel file along with their compliance report, but rather a lot of states included data in tables within the report. Amendment 3 does require state data to be submitted in an Excel file in a format that is based on the stock assessment needs.

This is relevant to the next item, so I'll just move on to that. The last several years, the PRT and the Technical Committee have continued to express some concerns with the difficulty of preparing and reviewing the compliance reports for these species, because they contain such a large quantity of information.

In an effort to streamline the reports, while making sure that all required information is still reported on an annual basis, the PRT is recommending using this basic outline for the reports, and having the body of the compliance report focus solely on answering the question of whether the state meets all of the requirements of the FMP for that fishing year or not.

There is more detail in the FMP review on the recommended changes that the PRT is asking for. But the main takeaway is that they are recommending moving the bulk of details from the body of the compliance reports, and instead moving things like monitoring results into the Excel spreadsheet, as recommended or required in Amendment 3.

That would accompany the compliance report, and then moving copies of regulations and detailed descriptions of the Fishery and Monitoring Program into appendices. Following this recommendation, the PRT is planning to develop a template, a new template for the compliance reports, which will be sent to the Board with a compliance report reminder this year, and staff will work with the states to make sure that this new template is being followed.

With that information, the action for the Board to consider today is approval of the shad and river herring FMP review for the 2019 fishing year, state compliance reports, and de minimis status requests for Maine, New Hampshire, Massachusetts and

Florida, as recommended by the PRT. That is the end of my presentation.

CHAIR ARMSTRONG: Thank you, Caitlin, any questions for Caitlin?

MS. KERNS: I don't see any hands raised. Mr. Chairman, I'm just going to really quickly, since I'm getting several e-mails about it. The vote count for the last vote was 10 in favor, not 9 in favor; just so it is corrected on the record.

CHAIR ARMSTRONG: Thank you. I'll say it again for the record. **The corrected vote count for the last motion we voted on was 10 to 8, not 9 to 8.** Anyway, let's see where we're at. Would someone have a motion to approve the review of the FMP, the state compliance reports and the de minimis requests?

MS. KERNS: We have John Clark.

CHAIR ARMSTRONG: Motion by John Clark, a second?

MS. KERNS: Cheri Patterson.

CHAIR ARMSTRONG: Cheri Patterson, thank you. Any discussion?

MR. CLARK: Do you need it read into the record, Mr. Chair?

CHAIR ARMSTRONG: Yes, please.

MR. CLARK: Okay, move to approve the fishery management plan review for the 2019 fishing year, state compliance reports and de minimis requests from Maine, New Hampshire, Massachusetts and Florida.

CHAIR ARMSTRONG: Thank you. Any discussion?

MS. KERNS: No. No discussion.

CHAIR ARMSTRONG: Are there any objections to approving this motion?

MS. KERNS: I see no objections.

CHAIR ARMSTRONG: Motion is approved by consensus.

REVIEW AND POPULATE THE ADVISORY PANEL MEMBERSHIP

CHAIR ARMSTRONG: Thank you, next item, last item is to review and populate the AP membership. Tina.

MS. TINA L. BERGER: Good morning everyone! Yes, I have two nominations to the Shad and River Herring Advisory Panel for your consideration and approval. They are Dr. Ed Hale of the University of Delaware Sea Grant, and Eric Roach, a recreational angler from New Hampshire. Thank you.

CHAIR ARMSTRONG: Toni, do we need a motion, or can we approve these appointees by consensus without a motion?

MS. KERNS: Good to have that motion, but you can approve that motion by just a verbal consensus. You have Justin Davis with his hand up.

CHAIR ARMSTRONG: Go ahead, Justin.

DR. DAVIS: I would move to approve nominations to the Shad and River Herring Advisory Panel for Dr. Ed Hale from Delaware, and Eric Roach from New Hampshire.

CHAIR ARMSTRONG: A second.

MS. KERNS: You have Roy Miller.

CHAIR ARMSTRONG: Thank you. Any discussion?
MS. KERNS: No discussion, no hands.

CHAIR ARMSTRONG: Is there any objection to approving this motion?

MS. KERNS: No hands.

CHAIR ARMSTRONG: The motion is approved by consensus. Leads us to the last item. Is there any Other Business to bring before this Board?

MS. KERNS: You have Doug Haymans with his hand up.

MR. HAYMANS: I don't know, this is simply a clarification for the statements made a moment ago about the vote. Just to clarify the record. You suggested that the 10-8 vote was for the motion previous, when in fact we had a motion and a vote over the Habitat Plan in between that, and the Technical Committee recommendation. I just wanted to make sure that it was clear that the 10-8 vote was regarding the Technical Committee, not the Habitat vote.

CHAIR ARMSTRONG: Thank you, Doug. That was an oversight. Let me state again, the motion was on Item 5, right that wound up being 10-8. Is that right, Caitlin?

MS. STARKS: Yes, Mr. Chair, on the motion to task the Technical Committee with developing a guidance document.

CHAIR ARMSTRONG: Yes, okay. Was that enough discussion for the record?

MS. KERNS: Great.

CHAIR ARMSTRONG: Any other business before the Board?

MS. KERNS: Tom Fote.

CHAIR ARMSTRONG: Go ahead, Tom.

MR. THOMAS P. FOTE: I make a motion to adjourn.

CHAIR ARMSTRONG: Do we have a second?

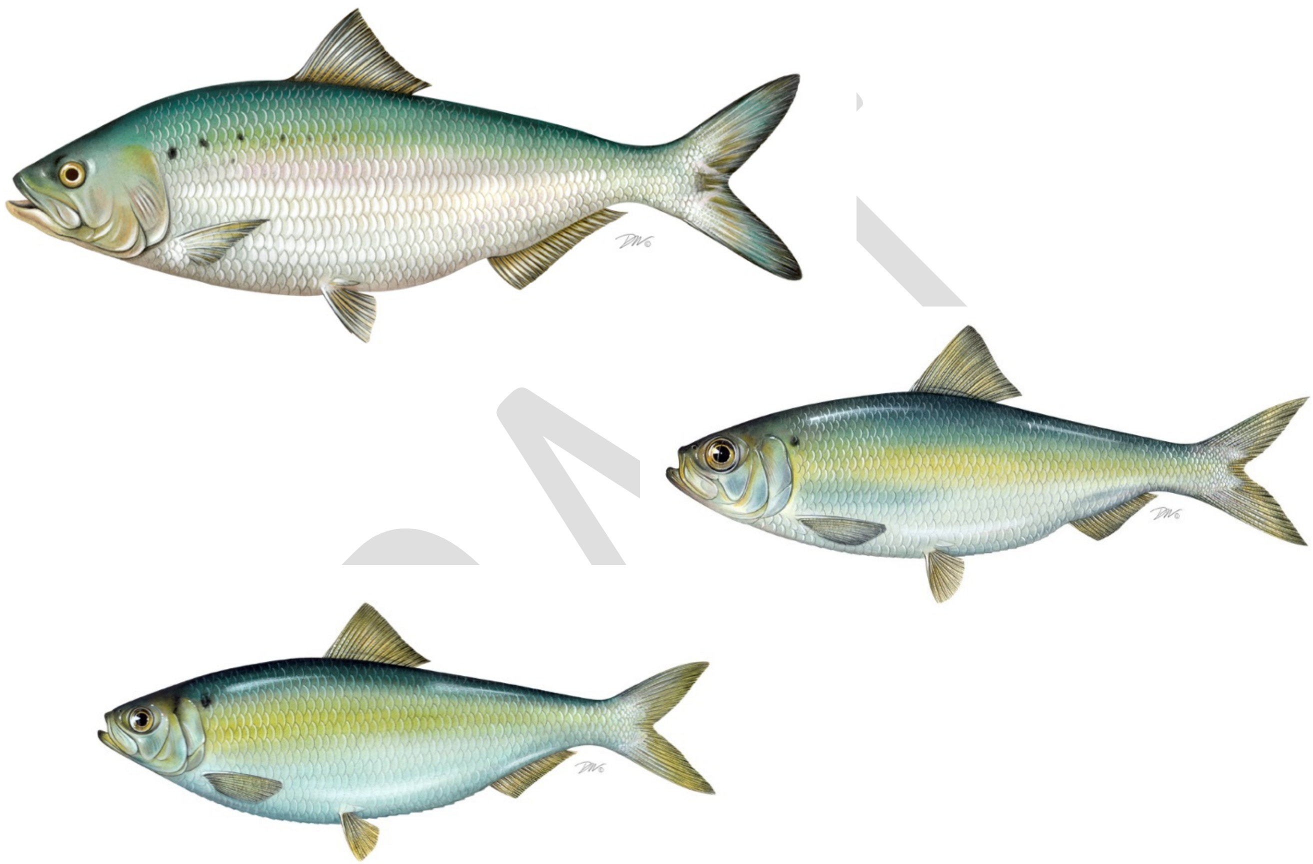
MS. KERNS: Allison Colden.

ADJOURNMENT

CHAIR ARMSTRONG: I assume there are no objections to adjourning. Seeing none; we are adjourned.

(Whereupon the meeting convened at 11:20 a.m. on February 4, 2021.)

Technical Guidance for Implementation of Amendments 2 and 3 to the Shad and River Herring Fishery Management Plan



March 2021

Sustainable and Cooperative Management of Atlantic Coastal Fisheries

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I. INTRODUCTION

Shad and river herring are managed under the Atlantic States Marine Fisheries Commission's (Commission) Interstate Fishery Management Plan (FMP). River herring (alewife and blueback herring) are managed under Amendment 2 to the FMP (2009), while American shad are managed under Amendment 3 to the FMP (2010). The management unit covers state waters along the U.S. Atlantic coast from Maine to Florida, and includes all 15 Atlantic coastal states as well as the Potomac River Fisheries Commission (PRFC) and the District of Columbia (DC).

Amendment 2 was approved by the Shad and River Herring Management Board (Board) in May 2009 with the goal of restricting the harvest of river herring due to observed declines in abundance. The Amendment prohibited commercial and recreational river herring harvest in state waters beginning January 1, 2012, unless a state or jurisdiction has a sustainable fishery management plan (SFMP) reviewed by the Technical Committee and approved by the Board. The Amendment defines a sustainable fishery as "a commercial and/or recreational fishery that will not diminish the potential future stock reproduction and recruitment." Catch and release only fisheries may be maintained in any river system without an SFMP. SFMPs for river herring have been approved by the Management Board for Maine, New Hampshire, Massachusetts, New York, and South Carolina. Amendment 2 also required states to implement fishery-dependent and independent monitoring programs.

In February 2010, the Board approved Amendment 3 in response to the 2007 American shad stock assessment, which found most American shad stocks at all-time lows. The Amendment requires similar management and monitoring for shad as Amendment 2 does for river herring. Specifically, Amendment 3 prohibits commercial and recreational harvest of shad in state waters after January 1, 2013, unless a state or jurisdiction has an SFMP reviewed by the Technical Committee and approved by the Board. Amendment 3 uses the same definition for a sustainable fishery as Amendment 2, and also allows for catch and release only fisheries in any river system (irrespective of an approved SFMP). SFMPs for shad have been approved by the Board for Massachusetts, Connecticut, the Delaware River Basin Fish Cooperative (on behalf of New York, Delaware, New Jersey, and Pennsylvania), PRFC, North Carolina, South Carolina, Georgia, and Florida. All states and jurisdictions are also required to produce American shad habitat plans, which identify local significant threats to American shad critical habitat and include a plan for mitigation and restoration.

In the fall of 2017, the Shad and River Herring Technical Committee (TC) identified several inconsistencies between state SFMPs and the requirements of Amendments 2 and 3. As a result, the Board tasked the TC with developing proposed improvements to Amendments 2 and 3 with regard to the five items:

1. Management and monitoring of rivers with low abundance and harvest of shad and river herring
2. Standardization of Sustainable Fishery Management Plan (SFMP) requirements: content, metrics, and management responses to triggers

3. Incorporation of stock assessment information into SFMPs and discussion on the timeline for renewing plans
4. Clarification of de minimis requirements as they pertain to SFMPs
5. Review of the number of years of data are required before developing a SFMP

The Board reviewed the TC recommendations in February 2021. The Board subsequently directed the TC to develop a technical guidance document to ensure that implementation of the Amendment 2 and 3 requirements related to the issues outlined above is consistent with the TC recommendations.

II. TECHNICAL GUIDANCE FOR IMPLEMENTATION OF AMENDMENTS 2 AND 3

The following sections include guidelines recommended by the Technical Committee for developing and evaluating state management programs for shad and river herring.

A. Guidance for Management and Monitoring of Rivers with Low Abundance and Harvest

Regardless of their size, commercial fisheries should continue to be addressed as indicated in the FMP (i.e. directed commercial harvest should always require an approved SFMP or Alternative Management Plan if appropriate).

With regard to recreational fisheries, the FMP is somewhat ambiguous as to the conditions that necessitate approval of an SFMP. Amendments 2 and 3 require that all recreational fisheries that do not have an approved sustainable management plan in place must be closed (or catch and release only). However, for a state that has no known recreational fishery targeting a particular species, but has historical records of that species' presence, the FMP is not clear on whether a lack of regulations restricting recreational harvest conforms to the requirements of the FMP.

To provide states with additional guidance on the management of recreational fisheries in systems with unknown or low abundance and harvest, the TC developed a framework for determining the appropriate management program for recreational fisheries based on harvest and monitoring information available for a given fishery or stock. The following matrix summarizes the framework, which is further explained below.

Recreational Harvest Information	**Monitoring Data to Support SFMP**	
	Sufficient	Insufficient
None (Species Absent)	1. NA	2. AMP
Unknown (Species Present)	3. SFMP	4. AMP/Catch & release
Known/ Suspected	5. SFMP	6. Catch & release

The status of information on recreational harvest and fisheries-independent (FI) monitoring data produce one scenario for species absence and five possible scenarios for a system where shad or river herring species may be present. The Technical Committee should evaluate the appropriateness of a particular management approach (i.e. no regulations, catch and release regulations, Alternative Management Plan, or SFMP) for each of these scenarios according to the following characterization of harvest information and monitoring data. It should be noted that catch and release only regulations or other regulations that explicitly prohibit recreational harvest are acceptable in any of these scenarios, as per the FMP.

Scenario 1: The species is considered absent or functionally absent, and this is based on sufficient monitoring data to detect the species.

→ In this scenario, the species is considered "functionally absent" if it is documented at such low levels or encountered so infrequently that it is reasonable to assume current environmental or habitat conditions cannot support a population at any level. For systems that fit this description, there should be no recreational harvest of the species due to its absence, and that should be supported by monitoring data. Therefore, the TC concluded that no regulations for recreational fisheries are needed. If the species in question were to become present (e.g., population restoration) the state must notify the Board and pursue one of the management approaches described below.

Scenario 2: The species is thought to be functionally absent, but there are insufficient monitoring data to support or confirm this conclusion.

→ For systems that fit this scenario, where there is no known population of the species, and consequently no suspected recreational harvest, but where the FI data are not adequate to determine the validity of the assumption that the species is functionally absent, the TC agreed that a state or jurisdiction must take one of two approaches. The first approach is that the state or jurisdiction could implement regulations that prohibit harvest, (i.e. catch and release only regulations) as a precautionary measure. This approach may prevent possible harvest from occurring in the absence of appropriate monitoring. The second approach is that recreational harvest in the system could remain unregulated, or allowed (e.g., under statewide harvest regulations for the species) through a Board-approved Alternative Management Plan (AMP). Use of AMPs is described in more detail later in this document, but generally, the AMP should include a justification for maintaining an unregulated status or regulations that permit recreational harvest, such that it is clear to the Board's satisfaction that the proposed regulations, or lack thereof, will be conservationally equivalent to catch and release only regulations. If new information or monitoring data were to indicate that the species had become present, the state must notify the Board and resubmit the proposal to the TC with updated information and rationale for evaluation.

Scenario 3: The species is present but recreational harvest information is unavailable to determine whether harvest occurs. There are monitoring data that can be used to monitor trends in the population and/or develop SFMP metrics.

→ For systems with known populations of the species where recreational harvest is unable to be determined due to a lack of recreational monitoring, the state may use an SFMP as long as there are sufficient monitoring data to develop appropriate sustainability metrics, as determined by the TC. If there are sufficient system-specific FI monitoring data and/or data from commercial monitoring such that trends in abundance or indices of abundance (e.g., CPUE) could be monitored and a sustainability metric could be developed, management under a Board-approved SFMP with system-specific metrics would be appropriate. Additionally, an SFMP may also be appropriate for a system without sufficient system-specific monitoring data if the TC agrees it would be appropriate to use data from other systems to develop regional or statewide sustainability metrics. The TC is responsible for determining whether monitoring data are sufficient or insufficient for their proposed uses.

Scenario 4: The species is present, recreational harvest information is unavailable to determine whether harvest occurs, and there are insufficient monitoring data that can be used to monitor trends in the population and/or develop SFMP metrics.

→ For systems with known populations of the species where recreational harvest is unable to be determined due to a lack of recreational monitoring, and there are insufficient system-specific monitoring data or appropriate data from other systems (FI or rec/commercial FD), the state or jurisdiction must either prohibit harvest though catch and release only regulations or other measures, or allow recreational harvest under a Board-approved AMP. In the case that the TC does not think system-specific data or state-level data are appropriate for use in an SFMP, but may provide sufficient justification that allowing recreational harvest will not contribute to overfishing of the resource or inhibit restoration of the resource, then the state may propose an AMP to permit recreational harvest. However, if the TC does not believe there is adequate information to demonstrate that permitting recreational harvest will not contribute to overfishing or inhibit restoration of the resource, then catch and release only regulations are recommended.

Scenario 5: The species is present and recreational harvest is either known to occur or suspected. There are monitoring data that can be used to monitor trends in the population and/or develop SFMP metrics.

→ For systems with known populations of the species where recreational harvest is known or suspected, and where the TC agrees that there are sufficient monitoring data to develop appropriate sustainability metrics, management of recreational harvest under a Board-approved SFMP is appropriate. "Known" harvest is that which is recorded in official surveys or reports, whereas "suspected" harvest is identified through anecdotal or historic information in systems without official monitoring of recreational harvest. If there are sufficient system-specific FI monitoring data and/or data from commercial monitoring such that trends in abundance or indices of abundance (e.g., CPUE) could be monitored and a sustainability metric could be developed, defining system-specific sustainability metrics and targets/thresholds in the SFMP would be appropriate. Alternatively, if there are not adequate system-specific data to develop SFMP metrics, then an SFMP using data from other systems to develop regional or statewide sustainability metrics may be appropriate. The TC is responsible for determining whether monitoring data are sufficient or insufficient for their proposed uses.

Scenario 6: The species is present and recreational harvest is either known to occur or suspected, but monitoring data are unavailable or insufficient for developing SFMP metrics.

→ For systems with known populations of the species where recreational harvest is known or suspected, if the TC does not agree that there are sufficient monitoring data to develop appropriate sustainability metrics, then recreational harvest should be explicitly prohibited under catch and release only regulations or other measures. This is consistent with Amendments 2 and 3, which require an approved SFMP that demonstrates the stock could support a recreational fishery that will not diminish potential future stock reproduction and recruitment in order to allow recreational harvest.

B. Standardization of Sustainable Fishery Management Plan Requirements

To increase consistency across states and jurisdictions in the content, metrics, and management responses to triggers that are included in SFMPs, the TC recommended guidelines for SFMPs related to the following three issues: 1) the level of detail required in SFMPs on the management response that would be implemented should the stock fall below a defined sustainability target or threshold; 2) when a state may relax restrictions implemented in response to a stock falling below the sustainability target/threshold; and 3) management of interjurisdictional waterbodies.

1. Management responses to SFMP triggers

Currently, Amendment 2 states that "If a stock is below optimum level the management plan must detail restrictions that will be enacted to allow for an increase in spawning stock abundance and juvenile recruitment" (p. 93). Amendment 3 includes an approved framework for SFMPs, which includes "discussion of management measure(s) to be taken if sustainable target is not achieved within indicated timeframe" (p. 41). However, the Amendments do not provide additional guidance on the level of detail that SFMPs should include when describing the management measures that will be taken should the stock fall below a defined sustainability target or threshold. To improve the strength and consistency of SFMPs for shad and river herring, the TC recommends that management responses in SFMPs and AMPs be developed and evaluated in accordance with the following guidance; the underlined portions are modified from the original language in the Amendments to provide more detail on acceptable management responses and the process for notifying the Board and implementing responses:

"*States and jurisdictions must also submit a sustainable fishery management plan (SFMP) that describes how the fishery will be conducted and annually monitored in order to show that the sustainability target(s) are being achieved. The frame of reference for determining the optimum level at which to set the sustainability target(s) will vary from system to* *system, but should be based on an appropriate time scale. States should develop their sustainability targets within this general framework. The Technical Committee is responsible for developing a standard optimum level and timeframe basis.*

If a stock is at optimum levels, then that level will need to be sustained. The SFMP must detail restrictions that will be enacted to allow for an increase in spawning stock abundance and juvenile recruitment if a stock is, or falls below, the optimum level. Such restrictions may include any of the following: fishery closures, harvest or effort restrictions, catch and release only regulations (for recreational fisheries), season changes, area closures, gear restrictions, etc. A plan may provide multiple options for restrictions that will be enacted if a stock falls below the optimum level, however, each option should allow for an increase in spawning stock abundance and juvenile recruitment.

If a stock falls below the sustainability target or threshold identified in the SFMP, the state must notify the Board in the next annual compliance report, and pursue implementation of the specified management response for the following calendar year."

The TC did not recommend additional requirements or restrictions be placed on the type of sustainability metrics that can be used in SFMPs. The group agrees that states/jurisdictions should be able to propose the most appropriate metrics for their specific systems, which would then be subject to TC evaluation and Board approval.

2. Relaxing management restrictions

The TC also developed additional guidance on when a state may relax restrictions implemented in response to a stock falling below the sustainability target/threshold. Currently, Amendments 2 and 3 include language to this effect: "Proposals to reopen closed fisheries may be submitted as part of the annual Compliance Report, and will be subject to review by the Plan Development Team, Technical Committee and Management Board." In addition, the TC recommends states and jurisdictions adhere to the following standard for relaxing restrictions:

"*If a state has implemented a management restriction in response to the stock falling below the sustainability target(s), the management restriction must stay in place until the sustainability target(s) have been met for at least 5 consecutive years of sufficient data collection*."

3. Interjurisdictional management guidance

Regarding management of waterbodies shared by one or more jurisdictions, Amendments 2 and 3 provide limited guidance. Amendment 2 states, "Targets for river systems managed by more than one state/jurisdiction should be cooperatively developed" (p. 92). Amendment 3 states, "For states and jurisdictions which share a river or estuary, agencies should include those monitoring programs conducted or planned by the agencies, applicable agency regulations, and habitat and habitat threats applicable to the state or jurisdiction's waters. In shared water bodies where there is a management cooperative, the cooperative or a member state or jurisdiction can be appointed to write the Implementation Plan" (p. 40). To further clarify and streamline the process for developing SFMPs for waterbodies shared by one or more jurisdictions, the TC recommends the states and jurisdictions adhere to the following guidance:

> "*Targets for river systems managed by more than one state or jurisdiction should be cooperatively developed, such that shared systems are not managed independently by each jurisdiction using unique targets and/or monitoring data. Instead, one shared management plan may be submitted cooperatively by multiple jurisdictions sharing one system, including details on management measures and monitoring for/by each jurisdiction. Alternatively, one jurisdiction may be appointed to submit the plan for a shared system; for example, if one state/jurisdiction is the primary source of fishery-dependent and/or fishery-independent data for a shared system, that state may include the shared system in their state management plan, and include information for the other jurisdictions which share the water body. When possible, fisheries conducted in shared water bodies by harvesters permitted by different jurisdictions should be subject to consistent management measures.*"

C. Incorporation of Stock Assessment Information into SFMPs and Plan Renewal Timeline

The TC will continue to review information on required and ongoing monitoring efforts performed by states and jurisdictions for each species and system, and develop recommendations for improvements to data for use in SFMPs and assessments. Some concern has been expressed among TC members that for many systems there is inconsistency between the information used to assess stock status through the stock assessment and that used to develop sustainability metrics for SFMPs. However, the TC did not conclude that states/jurisdictions should be required to use the stock assessment information to develop sustainability metrics for SFMPs (e.g. benchmarks based on total adult mortality).

Amendments 2 and 3 require all SFMPs to be regularly reviewed, assessed and updated as needed on five-year basis. The TC discussed the timeline for updating plans and recommended maintaining the five-year timeline for renewing both SFMPs and AMPs.

D. Clarification of *De Minimis* Requirements as They Pertain to SFMPs

The TC recommends maintaining the current *de minimis* criteria and exemptions for states with *de minimis* status. Under Amendments 2 and 3, states that report commercial landings of river herring or American shad, respectively, that are less than 1% of the coastwide commercial total are exempted from sub-sampling commercial and recreational catch for biological data. *De minimis* states are still required to implement an approved SFMP or AMP consistent with the FMP requirements in order to maintain any commercial or recreational fishery where harvest is permitted.

E. Years of Data Required Before Developing an SFMP

The TC discussed how many years of data in a time-series are acceptable in order to establish a sustainability metric in an SFMP. The TC recommended development and evaluation of SFMP sustainability metrics consistent with the following standards for each species, based on species biology and statistical value:

- For shad, a minimum of ten years of data should be required to establish a primary sustainability metric in an SFMP or AMP. The TC may have some discretion in evaluating state proposals that include sustainability metrics derived from fewer than ten consecutive years of data.

- For river herring, the standard for acceptable time-series length for data being used to establish a sustainability metric should be ten consecutive years. If additional information is provided to justify the use of a shorter time-series for establishing an SFMP metric, the TC may accept a time series trend of 7-9 years, with consideration of exploitation rate, stock size, or other relevant factors.

F. Additional Recommendations for Implementation of the Shad and River Herring FMP

Beyond the five areas identified in the original Board task, the TC discussed two additional areas of the FMP that could benefit from additional guidance: the use of Alternative Management Plans (AMPs) and statewide recreational possession limits.

1. Use of Alternative Management Plans

The TC discussed the Amendments' characterization of the use of "alternative management" regimes or programs. Both Amendments essentially provide the same language, which states that the Management Board can approve an alternative management program proposed by a state or jurisdiction if the state or jurisdiction can show to the Management Board's satisfaction that the alternative proposal will have the same conservation value as the measure contained in the amendment or any addenda prepared under adaptive management. The Amendments also indicate that the TC, under the direction of the Plan Review Team, will review any alternative management program proposals and provide the Management Board its evaluation of the adequacy of the proposals. However, the Amendments do not contain further guidance on when it is appropriate to apply an alternative management program or what type of information such a plan should include. In order to establish a more standard process for reviewing proposed AMPs, especially when applied to recreational fisheries, the TC developed the following guidelines:

- The TC recommends that AMPs include the following components:
    - A statement explaining why an SFMP cannot be used (e.g. data availability)
    - Justification that the proposed management program will have the same conservation value as the current FMP measures. For commercial fisheries, this is equivalent to the use of an SFMP as described in the FMP and in accordance with the additional guidance in this document. For recreational fisheries, this is permitting recreational harvest under an approved SFMP, or catch and release only regulations, consistent with the guidance provided in Section II.A of this document.
    - Explanation of how the state will determine if or when an AMP is no longer appropriate, including description of the data sources that will be monitored, and the trigger that will be used based on those data sources. For example, for a recreational AMP justified on the assumption that no harvest is occurring despite

being permitted, a condition such as three years of recorded recreational harvest, or a defined level of abundance from fishery-independent surveys could be used as a trigger to reevaluate the AMP.

- Description of the management response that will be implemented if this trigger is met. For example, if harvest is documented through a creel survey for three consecutive years, the AMP could specify that catch and release only regulations will be implemented statewide or for specified systems until an SFMP is developed and approved.
- If a management trigger identified in the AMP is met, the state must notify the Board in the next annual compliance report, and pursue implementation of the specified management response for the following calendar year.

2. Statewide recreational possession limits

The TC also discussed the use of statewide recreational possession limits for shad and river herring. In previous TC and Advisory Panel meetings, some TC and AP members had raised the question of whether it would be appropriate to allow limited recreational harvest in systems without an SFMP/AMP using a low statewide bag limit. Ultimately, the TC agreed that this would not comply with the requirement and intent of Amendments 2 and 3, and that any recreational harvest should be managed under an approved SFMP or AMP. The rationale is that unmonitored systems could experience unchecked recreational fishing pressure which could be detrimental to small stocks. If a state wishes to apply a statewide recreational bag limit, the state must have an approved SFMP or AMP, and all unmonitored systems must be subject to management responses (e.g. closures, harvest restrictions) that are triggered by available sustainability metrics. For example, if a state has a statewide recreational bag limit, the SFMP should require the closure of recreational harvest (e.g. catch and release only regulations) for all unmonitored systems if any of the approved SFMP metrics falls below the sustainability target. Additionally, the TC recommends that AMPs that include statewide recreational bag limits or no recreational regulations must include a trigger (e.g., observed recreational harvest, or an increase in a fishery-independent abundance index) to implement catch and release only regulations or to propose an SFMP (if sufficient data are available).

Atlantic States Marine Fisheries Commission

1050 N. Highland Street • Suite 200A-N • Arlington, VA 22201
703.842.0740 • 703.842.0741 (fax) • www.asmfc.org

MEMORANDUM

TO: **Shad and River Herring Management Board**

FROM: **Shad and River Herring Technical Committee**

DATE: **April 1, 2021**

SUBJECT: **Recommendations on Addressing Fish Passage Performance for American Shad and River Herring Restoration**

Background

The status and trends of American shad and river herring stocks on the Atlantic Coast are considered at "all time low levels of abundance" based upon stock assessments completed for American shad in 2007 and 2020 and for river herring in 2012 and 2017. These assessments demonstrate that despite significant fishery restrictions implemented under the Commission's Fishery Management Plan (FMP) for Shad and River Herring, many stocks are not showing detectable improvements. The assessments identify several factors that may play primary roles in the reported stock status and trends. In particular, the 2020 American Shad Stock Assessment and Peer Review Report (Assessment Report) provides the most detail on the role of barriers to migration, and includes the first quantitative assessment of associated habitat loss and population impacts from existing barriers.

The Assessment Report examines shad habitat and migration barriers, and fish passage performance as of 2018 provided by Shad and River Herring Technical Committee (TC) members. Using standardized data and simulation modelling, the analysis quantified the impacts of barriers and fish passage in three sub-population areas based on shad life history and habitat (roughly New England, Mid-Atlantic, and South Atlantic). Simulation modelling was conducted to assess effects on spawner population size under three scenarios: 1) no barriers, 2) first barrier with no passage, and 3) realistic fish passage performance measures applied to barriers (i.e., upstream passage efficiency of 50%).

The analysis determined that overall, dams completely or partly block nearly 40% of the total historical American Shad habitat; within the northern iteroparous, southern iteroparous, and semelparous sub-regions of the coastwide metapopulation, respectively, American shad habitat is currently 42, 30, and 28% of what it was historically. The model results of the "no barriers" scenario yielded an estimated spawner production potential 1.7 times greater than that yielded by the scenario assuming no passage at the first barrier: 72.8 million versus 42.8 million fish. The results of the third model scenario, which applies "realistic" (i.e., current) fish passage efficiencies, resulted in a gain of less than 3 million fish, suggesting that current passage only provides a minimal improvement in spawner potential compared to no passage. Consequently, the Assessment Report concluded that "losses in [spawner production] potential are significant in each state and region."

Technical Committee Request

The Shad and River Herring TC feels strongly that the following actions are needed to reduce the negative effects of barriers to migration on shad, river herring, and other migratory fish populations along the Atlantic Coast to provide increased opportunities for population recovery:

1) Dam/barrier removals as the preferred approach to restore fish species habitat access for population restoration and for habitat restoration benefits. When dam removal is not an option,
2) The development and use of fish passage performance standards in river systems based on available data, fish passage modeling tools, and fish passage expertise is recommended. If the required information to develop performance standards are not available, we recommend and support their development for such purposes and applications.

The TC recommends the Commission send letters to the agencies with relevant authorities to request prioritization of these actions.

Rationale

The Assessment Report provides an extensive review of available literature and discussion on the topic of barriers and the many aspects of fish passage. Specifically, it highlights the issues with both outdated approaches and facilities designs/operations that are not effective by a variety of management measures (e.g., percentage of arriving fish passing) and lack of rigorous evaluations. Consequently, without changes in how fish passage objectives are generically defined as *safe, timely, and effective*, and evaluated, management and restoration goals are not likely to be achieved.

The most challenging aspect is the number of barriers fragmenting historic habitat in many systems which compounds any individual barrier/facility effects. Barriers and associated hydroelectric facilities may cause delays, injuries or stress, and mortality to both upstream and downstream migrants at both the juvenile and adult life stages. The cumulative effect barriers have on achieving ASMFC Management goals should be recognized as one of the largest and most pervasive obstacles to the recovery of American shad.

The Shad and River Herring FMP and recent stock assessments all speak to the important influence and problems associated with barriers, fish passage, and related impacts for these species. However, the ASMFC has been largely limited to addressing directed fisheries by requiring Sustainable Fishery Management Plans for commercial or recreational fisheries under Amendments 2 and 3. Over the next several years, an increased number of hydropower license expirations and relicensing projects will occur for federally licensed hydropower projects, which will affect Commission management and restoration goals for not only American shad and river herring, but also American eel and other anadromous species. Given that Federal Energy Regulatory Commission (FERC) license terms and conditions operate for 30-50 years, upcoming relicensing projects provide critical opportunities to ensure that the necessary passage and protection measures, as well as adaptive management strategies, are established to meet fish restoration goals and objectives.

The U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS) both have fish passage prescription authority under the Federal Power Act. States also often have the ability to use a required Water Quality Certificate during relicensing to address fish passage. ASMFC relies on passage counts and population benchmarks to provide guidance for science-based management of shad and river herring. This quantitative approach needs to be applied to fish passage, and has been requested by FERC: "*Commerce and Interior have not included any specific performance standards that would be used to test the effectiveness of the fish passage facilities…Without specific performance standards to analyze, there is no basis for assessing the benefits of effectiveness testing for fish passage and determining whether effectiveness testing would or would not provide benefits to alosines…*" (FERC 2018). The Assessment Report provides a strong justification for the need and benefits of requiring science-based fish passage performance criteria to achieve management goals that are not possible with status quo approaches and unquantified performance standards. Improved passage performance is an achievable goal given the current state of knowledge on fish behavior, swimming performance, and fish passage engineering. Improved passage performance criteria will be essential to provide a basis for defining what is safe, effective and timely, considering that fish passage directly impacts the ability of the ASMFC to achieve its management goals and objectives.

American Shad Habitat Plan for Massachusetts Coastal Rivers

Submitted to:

Atlantic States Marine Fisheries Commission

Prepared by:

Bradford C. Chase, John J. Sheppard, Benjamin Gahagan and Sara Turner

Massachusetts Division of Marine Fisheries
251 Causeway Street, Suite 400
Boston, MA 02114

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Introduction

American shad (*Alosa sapidissima*) habitat plans are required by the Atlantic States Marine Fisheries Commission through Amendment 3 of the Interstate Fishery Management Plan for Shad and River Herring. This report updates the first Massachusetts shad habitat plan reported in 2014 (MA DMF 2014).

American shad spawning runs in Massachusetts occur in two large rivers bordering multiple jurisdictions and six smaller sized coastal rivers. The Connecticut River and Merrimack River have relatively large runs of American shad that support recreational fisheries and are managed by multi-jurisdiction management plans (CRASC 1992; and MRTC 1997). The American shad habitat plans for the Connecticut River (CRASC 2014) and Merrimack River (MRTC 2010) are reported independently from this plan. The other coastal rivers with known spawning runs present are: Palmer River, Jones River, the Indian Head and South rivers in the North River watershed, Neponset River, and Charles River. The Taunton River had a robust shad run and fishery historically with recent evidence of a remnant run.

The principal threat identified for most shad runs in Massachusetts is **Barriers to Migration**. However, significant questions exist on the status of potential threats and issues such as water withdrawals and water quality impairment and require further investigation. The first MA shad habitat plan (MA DMF 2014) reported on the Palmer River and Charles River because among the six coastal runs they were identified as restoration priorities by the MA Division of Marine Fisheries (DMF). The Taunton River was included in the first shad habitat plan to encourage investigations on the population and habitat status. This update includes additional information on the Jones, North, South and Neponset rivers.

A synopsis of investigations on American shad spawning habitat requirements (Greene et al. 2009) reveals that although consensus is lacking, shad generally spawn well upstream of the tidal interface at mid-river runs in relatively shallow depths (< 4 m) with more apparent selection to water velocity (0.3 to 0.9 m/s) than to a specific substrate type.

Table 1. Massachusetts coastal rivers with American shad spawning runs.

River	Watershed	Total Drainage Area (km^2)	Present Migratory Access (rkm)	Present Spawning Habitat (rkm)	Restoration Potential (rkm)	Notes
Palmer River	Narragansett Bay	71	12.4	<5	10.5	with dam removal
Taunton River	Narragansett Bay	1456	62.0	45	0	no main stem barriers
Jones River	South Shore	77	12.0	8.5	0	recent restoration improvements
Indian Head River	South Shore	<100	6.0	2	5	with dam removal/and or passage improvements
South River	South Shore	<100	7.8	1	2	with dam removal/and or passage improvements
Neponset River	Boston Harbor	262	6.8	1	25	from 1970s DMF survey
Charles River	Boston Harbor	805	32.0	32	32	from 1970s DMF survey

Palmer River

Watershed Information. The Palmer River, located in Bristol County, MA, originates in the wetlands of northern Rehoboth (Figure 1) and flows south for approximately 27 river kilometers (rkm) through Swansea to its confluence with the Barrington River and discharges to Narragansett Bay in RI. Two impoundments created by dams are located along the course of the river: Shad Factory Pond and Perryville Pond. The former is a shallow 38-acre pond formed by a dam last rebuilt in 1912. The dam is located at 12.4 rkm with a drainage area of 71.2 km^2. Shad are known to spawn along an unknown proportion of the upper end of the river below the dam. Upstream of the dam, there is 10.5 rkm of potential spawning habitat before reaching the impassible Perryville Dam at 22.9 rkm. The habitat upstream of the Perryville Dam (Perryville Pond; 3.3 acres) has not been assessed but is thought to have low potential for shad. The watershed also supports spring spawning runs of white perch and river herring; and was documented in the 1970s as having spawning rainbow smelt and sea lamprey. The Palmer River presently has the last remaining recreational fishery for American shad in MA south of Cape Cod.

American Shad Status. No current population data are available. Fishery resource surveys were conducted by DMF and the MA Division of Fish and Wildlife (*MassWildilfe*) from 1968 to 1971 and by DMF in 1993. Water quality and creel information were collected in these surveys. Creel survey results are summarized in Table 1. In addition, shad were transplanted by DMF personnel from the Palmer River into the Mattapoisett River in 1968 (N = 78) and in 1969 (N = 80). Anecdotal reports suggest that recreational angling for shad continues in the Palmer River, although at low levels of catch and effort. Population and habitat monitoring were considered when the fish ladder was reconstructed at Shad Factory Pond in 2007; however, this work was not conducted.

Table 1. Summary of Palmer River shad creel surveys conducted between 1968 – 1971 and 1993.

Date	1968	1969	1970	1971	1993
No. Anglers	333	657	413	419	72
Total Catch	148	174	82	120	41
Hours Fished	660	1500	1297	915	108
Catch/Hour	0.22	0.12	0.06	0.13	0.38

Fish Ladder Specifications: A concrete weir and pool fish ladder was installed in 2007 by the Town of Rehoboth, Save the Bay, and several funding partners. The fish ladder was designed by the U.S. Fish and Wildlife Service (USFWS) and the project received technical assistance from the MA Office of Fishing and Boating Access and DMF. The fish ladder is approximately 320 ft. in length with 19 weirs and 16 ft x 3 ft pools. No monitoring of shad passage has been assessed at this location. The Perryville Dam in Rehoboth has no fishway and obstructs passage to unassessed habitat (Reback et al. 2004).

Regulatory Authority: The owner of the dam is responsible for repairing, operating, and maintaining the fish passage facilities as prescribed in M.G.L. Chapter 130 §19. Fish passage at the Shad Factory Pond fish ladder has been historically managed cooperatively by the Town of Rehoboth and the dam owner, the Bristol County Water Authority of Bristol, RI. Wetlands habitat and water quality protections are provided by M.G.L. Chapter 131 §40 and Commonwealth of Massachusetts Regulations (CMR) 10.00 and administered by the Massachusetts Department of Environmental Protection (*Mass*DEP).

Water Withdrawal Permissions: The Bristol County Water Authority maintains a water withdrawal registration (No. 4-26-247.05) issued by *Mass*DEP in the Narragansett Bay and Mt. Hope Bay Shore river basins to withdraw 2.7 million gallons per day (MGD) from three surface water sources (Swansea

Reservoir, Shad Factory Reservoir and Anawan Reservoir) for public water supply. Monthly withdrawal records are required for annual submission to *Mass*DEP.

Water Discharge Data: None currently. The West Branch of the Palmer River had a US Geological Survey gauge station (No. 01109200, drainage area 11.3 km^2) operating during 1962-1974. The monthly mean discharge in May for this period was 9.8 cfs; however, the short duration of the data series and long distance between the West Branch gauge location and Shad Factory Pond limit the data utility.

Water Quality Monitoring: *Mass*DEP assesses waterbodies by comparing water quality to Surface Water Quality Standards (SWQC), indentifying threats to habitats and recommending remedial actions (*Mass*DEP 2007). The Narragansett Bay watershed was last assessed during 2004-2008 (*Mass*DEP 2009); however, the Palmer River segment was listed as "Not Assessed" for its capacity to support aquatic life.

Shad Factory Pond Habitat Assessment. A habitat assessment of river herring spawning and nursery habitat in Shad Factory Pond was conducted by DMF and Save the Bay, a RI non-profit watershed organization, during 2016-2017 (Turner et al. *in Prep*). The assessment investigated water quality conditions in the pond and downstream fish passage conditions. Water quality criteria for dissolved oxygen, Secchi disc depth, pH, total nitrogen, and total phosphorus were exceeded in the lake. The assessment documented significant degradation in the pond due to high growth of the invasive water chestnut. The fishway at Shad Factory Pond had sufficient flow and depth for suitable passage during river herring migration periods. However, the degraded pond conditions would not provide suitable nursery habitat for river herring during summer months and not likely encourage shad passage to upstream riverine habitat.

ASMFC Shad Habitat Plan Framework

1.) Shad Habitat Assessment. No formal assessment of shad spawning and nursery habitat has been conducted in the Palmer River. Previous creel surveys documented a sportfishery for shad in the Palmer River that continues presently, although with low levels of participation, and with no evidence that shad are passing the fishway at Shad Factory Pond to upstream spawning habitat. Upstream of the dam, there is approximately 10.5 km of potential spawning habitat before reaching the impassible Perryville Dam at rkm 22.9. The habitat upstream of the Perryville Dam (Perryville Pond; 3.3 acres) has not been assessed but is thought to have low potential for diadromous species. Consideration was given to conducting shad electrofishing monitoring in the Palmer River during 2016-2017 although funding and staff limits did not allow this action to move forward.

2.) Threats Assessment. No formal threat assessments have been made for shad in the Palmer River watershed. A primary assumed threat to shad for this watershed is the Shad Factory Pond Dam as a **Barrier to Migration**. The fishway at Shad Factory Pond Dam was reconstructed in 2007 and specifically designed to pass shad. However, concerns have grown over water quality and invasive plant infestation in the pond. It is possible that present conditions prevent shad from migrating through the pond to potential upstream riverine habitat. Historically, a large shad commercial fishery occurred in the Palmer River. Belding (1921) reports that the initiation of trap fisheries in the tidal area of the Palmer River in the 1870s and 1880s quickly reduced the shad run to low levels of abundance by the 1910s. Historical overfishing and habitat quality are threats that should be considered along with migration barriers.

3.) Habitat Restoration Plan. Currently, DMF does not have an ongoing project or imminent plans to initiate a shad habitat restoration plan for the Palmer River. The Save the Bay has expressed an interest in investigating the feasibility of removing Shad Factory Pond Dam. If this concept moves forward, DMF would be supportive and potentially a partner in this restoration activity.

Recommended action:

Currently, DMF does not have an ongoing project or imminent plans to initiate an assessment of the Palmer River shad run. DMF did complete a habitat assessment of Shad Factory Pond in 2018 with results that support local interests in dam removal. We **recommend** the following actions for the Palmer River: (1) assessment of the amount and suitability of Palmer River habitat for shad spawning and rearing, (2) census counts of shad and river herring passing upstream into Shad Factory Pond, (3) passage efficiency at the Shad Factory Dam fishway and (4) the feasibility of fish passage improvements at the Perryville Dam.

Agency or Agencies with Regulatory Authority: Massachusetts DMF coastal waters diadromous fish, *MassWildlife* inland waters diadromous fish, and *Mass*DEP - wetlands and water quality protection.

Action actively being addressed by agency: The only action taken to date has been the preparation of an Operations and Maintenance Plan for the Shad Factory Dam fishway. A draft was sent to the dam owner in 2011 requesting comments. The dam owner did not respond to the inquiry.

Initial Habitat Goal: Conduct the shad spawning habitat assessment for the Palmer River upstream and downstream of Shad Factory Pond and assess species presence. If suitable upstream conditions are found, seek funding for passage efficiency studies at Shad Factory Pond and fish passage feasibility studies at Perryville Dam.

Timeline and Costs for Achieving Goals/Targets. None established. Funding is not presently available.

Possible metrics to evaluate progress: (1) comparison of water quality parameters to *Mass*DEP Surface Water Quality Criteria (SWQC) for supporting aquatic life; (2) census counts of shad and river herring into Shad Factory Pond using a locking box trap installed at the fish ladder exit; (3) passage efficiency evaluation using PIT tag study; (4) discharge range that provides suitable water depth and velocity in fishway and water depth and velocity at river habitats.

Potential setbacks/areas of concern: The watershed is part of an active water supply. The municipal needs for water compete directly with water needs for aquatic life, but the effects are unknown.

Other organizations: The Save the Bay was actively involved in the Shad Factory Pond habitat assessment and development of a dam removal project at that site. The Town of Rehoboth has expressed an interest in shad restoration in the Palmer River. The Bristol County Water Authority has an interest and responsibility to allow diadromous fish passage at Shad Factory Pond.

Taunton River

Watershed Information: The Taunton River is the largest river in southeastern Massachusetts and has no barriers that impede American shad passage along the 62 km main stem. The Taunton River includes a large drainage area (approximately 1,456 km^2) that is supported by numerous significant tributaries. The Taunton River, which is formed by the confluence of the Matfield and Town rivers in Bridgewater, passes the borders of more than 10 towns before reaching the tidal Mount Hope Bay which connects to Narragansett Bay (Figure 1). The watershed has a legacy of industrial pollution; yet is unique in Massachusetts with no dams along its entire main stem.

American Shad Status: Belding's (1921) anadromous fish survey of the early 20th century recognized historical shad runs in the Taunton River that were rendered commercially extinct due to industrial pollution. The next anadromous fish survey in the 1960s (Reback and DiCarlo, 1972) also cited pollution as the primary driver of low shad numbers in the Taunton system as opposed to dams. During this survey, additional work was done to identify shad habitat in the Taunton River. DMF surveyed the stream substrate from the Berkley Bridge in Dighton to the Jenkins Leatherboard Company dam in Bridgewater. The Berkley Bridge was the lower limit of salt water intrusion. They documented 45 rkm of potential spawning habitat in this stretch and highlighted the promising outlook for shad restoration. They also named the Segreganset River and Nemasket River as Taunton River tributaries with shad present. Reback and DiCarlo (1972) noted a shad stocking project in 1969 that transferred shad eggs from Connecticut River adults to the Nemasket River. The most recent DMF anadromous fish survey (Reback et al. 2004) echoes the potential for shad restoration in the Taunton River but recognized that shad stocking in the 1960s and 1970s with eggs and adults from the Connecticut River produced little evidence of success. Presently, the status of shad in the Taunton River watershed is unknown with some anecdotal reports of finding individual adult shad in the last decade.

Fish Ladder Specifications: No fishways in main stem Taunton River.

Regulatory Authority: In the absence of dams and fishways, the principal regulatory authority related to American shad is found with the state regulations of the DMF (coastal) and *MassWildlife* (inland). Wetlands habitat and water quality protections are provided by M.G.L. Chapter 131 §40 and CMR 10.00 and administered by *Mass*DEP.

Water Withdrawal Permissions: Three facilities have MA Water Management Act permits with authorized surface and groundwater withdrawals totaling 3.27 million gallons per day (MGD). Of these three facilities, the largest withdrawal at 3.03 MGD is for a municipal public water source.

Water Discharge Data: The main stem Taunton River has a USGS stream flow gauge in Bridgewater (No. 01108000, 676 km^2 drainage area). The average monthly discharge at the Bridgewater gauge station is 900 cfs for April and 554 cfs for May from the time series record of 1929-2020.

Water Quality Monitoring: *Mass*DEP assesses waterbodies by comparing water quality to Surface Water Quality Standards, identifying threats to habitats and recommending remedial actions (*Mass*DEP 2007). The Taunton River watershed was last assessed during 2004 (Rojko et al. 2005); with most of the potential main stem shad habitat listed as *Suitable* to support aquatic life or "Not Assessed".

ASMFC Shad Habitat Plan Framework

1.) Shad Habitat Assessment. The only assessment of shad spawning and nursery habitat in the Taunton River was conducted by DMF in the 1970s. This survey documented 45 rkm of potential spawning habitat in the Taunton River and highlighted the promising outlook for shad restoration. Recent exploratory work has been done in the Taunton River focusing on the documentation of shad presence.

2.) Threats Assessment. No formal threat assessments have been made for shad in the Taunton River watershed. As a river with the uncommon status in Massachusetts of no main stem dams, the threat of **Barrier to Migration** not a factor. Historical overfishing and industrial pollution were cited in past anadromous fish surveys as impacting shad populations in the Taunton River.

3.) Habitat Restoration Plan. DMF is currently working with the *MassWildlife* and the USFWS to prepare a scope for stocking shad in the Taunton River.

Recommended action:

Of the MA coastal rivers in this plan, the least information is known on the status of and threats to American shad in the Taunton River. DMF seeks more information on the presence of shad in the Taunton River, the status of potential shad habitat, and the influence of potential threats such as historical and present pollutant loading, and water quality impairment. We expect that a habitat survey and assessment would be useful for this watershed with methods potentially transferable to other watersheds in Massachusetts, but funding is not presently available. We **recommend** the following actions for the Taunton River: (1) assessment of the amount and suitability of habitat for shad spawning and rearing; and (2) continued monitoring to confirm the presence of a shad spawning run.

Agency or Agencies with Regulatory Authority: DMF coastal waters diadromous fish, *MassWildlife* inland waters diadromous fish, and *Mass*DEP - wetlands and water quality protection.

Action actively being addressed by agency: DMF is presently conducting river bank seining and boat electrofishing to document the presence of shad. Efforts are also underway to develop a cooperative shad stocking project with DMF, *MassWildlife* and the USFWS.

Initial Habitat Goal: No restoration actions are needed to expand habitat access in the Taunton River. Agency efforts will focus on confirming species status and developing a stocking plan in 2021.

Timeline and Costs for Achieving Goals/Targets. Juvenile American shad stocking is recommended for a six to eight years and would cost approximately $180,000-240,000 with partial reimbursement needed for the regional USFWS hatchery. Monitoring efforts would continue for at minimum of this duration to document changes in adult and juvenile American shad abundances in the river resulting from stocking efforts. Funding sources have not been identified presently.

Possible metrics to evaluate progress: (1) comparison of water quality parameters to MA SWQC for supporting aquatic life; and (2) discharge range that provides suitable water depth and velocity at river habitats.

Potential setbacks/areas of concern: The watershed is part of an active water supply and urbanized area with documented surface water quality and stormwater impairments. The municipal needs for water compete directly with water needs for aquatic life, but the effects are unknown.

Other organizations: The USFWS and *MassWildlife* are partners with ongoing shad monitoring and stocking plan development. Additionally, several towns have active river herring wardens that would likely take an interest and perhaps participate in future shad monitoring and restoration efforts as would The Nature Conservancy and the Taunton River Watershed Alliance, active non-profit groups that work to improve the aquatic resources of the Taunton River.

Jones River

Watershed Information. The Jones River flows for 12 rkm in a drainage area of 77 km^2 from Silver Lake in Kingston, MA, to Kingston Bay (Figure 2). At 634 acres, Silver Lake is the largest lake in the South Shore Drainage Area. The Jones River is the largest freshwater drainage flowing into Cape Cod Bay. Numerous dams have restricted diadromous fish passage in the Jones River watershed since the 18th century. The lowermost dam at Elm Street was removed in 2019. This dam had a 5-section Alaskan Steeppass fishway that was considered not favorable for shad passage. The next dam upstream at

Wapping Road had no fishway and was removed in 2011. The final dam at Forge Pond is the water control for the City of Brockton's water supply at Silver Lake. This dam had no fish passage until DMF installed a wood weir and pool fishway in 2019. The two dam removals and fishway installation in recent years greatly improved the potential for diadromous fish passage in the upper Jones River watershed.

American Shad Status. Accounts of shad in the Jones River mainly come from anecdotal reports of uncommon sportfishing catches, dead shad observed on the river bank, and schooling adult shad below the Elm Street Dam. Photographs of such accounts have been verified by DMF biologists in recent decades. Ten years of river herring counting at the Elm Street Dam fishway had not recorded observations of shad passing. A rainbow smelt fyke net monitoring series maintained by DMF at the tidal interface in the Jones River has caught two juvenile shad during a 17-year time series (DMF, unpublished information). No known sportfishery specifically targets shad in the Jones River. Collectively, these accounts suggest a remnant run with low numbers of shad presently in the Jones River.

Regulatory Authority. The owners of dams are responsible for repairing, operating, and maintaining the fish passage facilities in MA as prescribed in M.G.L. Chapter 130 §19. The City of Brockton signed a Memorandum of Agreement with DMF to install and operate a fishway at Forge Pond Dam in 2018. In 2019, a DMF Fishway Operation and Maintenance Plan was implemented for Forge Pond Dam. Wetlands habitat and water quality protections are provided by M.G.L. Chapter 131 §40 and CMR 10.00 and administered by the *Mass*DEP.

Water Withdrawal Permissions. The City of Brockton received State Legislation in 1899 to divert water from Silver Lake for their water supply. Their present Water Management Act registration allows the City to withdraw up to 11.1 MGD from Silver Lake and two connected reservoirs to provide nearly all water needs for over 150,000 citizens. This water supply activity routine results in no outflow from Silver Lake from July to October (Gomez and Sullivan 2013). Several cranberry bogs also have water withdrawal permissions in the watershed.

Water Discharge Data. The USGS maintains one stream flow gauge in the Jones River watershed in Kingston at Elm Street (No. 01105870, 4.3 rkm, 51.2 km^2 drainage area). The average monthly discharge at the Elm Street gauge is 56 cfs for April and 42 cfs for May from the time series record of 1966-2020.

Water Quality Monitoring. *Mass*DEP assesses waterbodies by comparing water quality to SWQC, identifying threats to habitats and recommending remedial actions (*Mass*DEP 2007). Recent assessments have listed Silver Lake as impaired due to flow alterations from water supply withdrawals.

Silver Lake Habitat Assessment. A habitat assessment of river herring spawning and nursery habitat in Silver Lake was conducted by DMF and the Jones River Watershed Association during 2008-2009 (Chase et al. 2013). The assessment investigated water quality conditions in the lake and downstream fish passage conditions. Water quality criteria for dissolved oxygen, pH, total nitrogen, and total phosphorus were exceeded in the lake. The most significant impairment documented was the lack of outflow at Forge Pond Dam during summer and early fall each year. No observations of shad were made during the assessment and no fish passage was possible at the two upper impassible dams at that time.

ASMFC Shad Habitat Plan Framework

1.) Shad Habitat Assessment. No formal assessment of shad spawning and nursery habitat has been conducted in the Jones River watershed. The removals of the Wapping Road Dam in 2011 and the Elm Street Dam in 2019 provide a significant opportunity for shad to increase access to upstream riverine habitat. The river gains flow moving downstream from groundwater and tributary contributions. The restored river channel from Elm Street to Wapping Road has riffle-pool conditions that appear suitable for shad spawning. This reach is approximately 1.5 km. The next reach from Wapping Road to Grove Street has moderate suitability for approximately 5 km. The final reach of approximately 2 km from Grove Street to the Forge Pond Dam has limited suitability due to shallow depths and reduced flow. Freshwater inputs upgradient of Silver Lake are managed for water supply purposes and not likely to provide additional shad habitat for fish that may pass into Silver Lake.

2.) Threats Assessment. No formal threat assessments have been made for shad in the Jones River watershed. The primary assumed threat historically was **Barriers to Migration**. This has been largely mitigated by the removal of the two lower dams that limited access to suitable spawning habitat. A temporary wood fish ladder was installed at Forge Pond Dam, the only remaining dam on the Jones River in 2019. Plans are underway to design and install a permanent fishway at Forge Pond Dam with associated pond dredging, improved attraction flow, and improved design for upstream and downstream passage. However, Silver Lake is not expected to provide additional shad habitat.

The most significant threat to shad may be the large municipal **Water Withdrawal** at Silver Lake that can degrade the upper watershed nursery habitat for shad for most of the season when juvenile shad would occupy this area. In addition to lower flow and channel depth, the chronically reduced flow allows the creation of debris jams and encroachment of wetland shrubs in the river channel. Over time, these obstructions trap sediment, fragment river channel and block fish passage. Sea level rise could be a factor in this watershed as evidence of higher tidal influence at Elm Street observed during over 30 years of DMF monitoring and the recorded pulses of new and full moon tides at the USGS gauge station.

3.) Habitat Restoration Plan. Currently, DMF does not have an ongoing project or imminent plans to initiate an assessment of the Jones River shad run or conduct a habitat restoration plan. Two areas of interest are a shad spawning and nursery habitat assessment in the river reaches made available by the recent dam removals, and population monitoring in response to the dam removals for several species of diadromous fish. The shad run in the Jones River may be the smallest among coastal rivers in MA. Funding is not available presently for new shad investigations.

Agency or Agencies with Regulatory Authority. Massachusetts DMF coastal waters diadromous fish, *MassWildlife* - inland waters diadromous fish, and *Mass*DEP - wetlands and water quality protection.

Action actively being addressed by agency. A stream maintenance plan was drafted by DMF in 2019 and approved by the Kingston Conservation Commission. Presently, DMF is working with the Jones River Watershed Association to improve river channel that could benefit shad spawning and nursery habitat. A Fishway Operations and Maintenance Plan for Forge Pond Dam was prepared in 2019 with the first year of application in 2020. The Jones River smelt fyke net monitoring series will be maintained with the potential to document changes in shad catch over time in response to the recent dam removals.

Initial Habitat Goal. Conduct the shad spawning habitat assessment for the Jones River from Elm Street to Grove Street. Match habitat assessments to shad population monitoring

Timeline and Costs for Achieving Goals/Targets. None established. Funding is not presently available.

Other organizations. The Jones River Watershed Association has been actively involved in natural resource stewardship in the Jones River for decades. This association is interested in participating in diadromous fish habitat and population monitoring that could benefit shad.

North River

Watershed Information. The North River watershed is the largest watershed in the South Shore coastal drainage area in Massachusetts with several significant tributaries within six towns (Figure 2). It contains two known tributaries that support shad spawning runs and fisheries: the South River and Indian Head River. The North River is formed at the confluence of the Indian Head River and Herring Brook in Pembroke. The Indian Head River flows for over 3 km from Factory Pond before meeting Herring Brook. There are no dams on the main stem North River. Shad can reach the Elm Street Dam at the Pembroke and Hanover border on the Indian Head River where a 4 ft Denil fish ladder was constructed to allow shad passage. The South River flows for 5.5 km from the Veteran's Park Dam in Marshfield where shad passage is possible but uncertain at a weir and pool fish ladder on the dam.

American Shad Status

South River. The South River presently has a shad spawning run that attracts low levels of sportfishing activity. However, historical records of this fishery are scant. Belding (1921) does not reference shad in his survey and Reback and DiCarlo (1972) simply mention that shad were present in the river in the 1960s. Recent DMF electrofishing for shad has documented the continuance of a well-defined shad run in the South River that aggregate below the Veteran's Park Dam. The Town of Marshfield is leading a cooperative investigation on the potential of removing the dam and installing a nature-like fishway, with feasibility work underway in 2020.

Indian Head River. Belding (1921) made no reference to shad in the Indian Head River, while noting the presence of several active mill industries with impassable dams and ongoing discharges of industrial waste. Reback and DiCarlo (1972) described an excellent sportfishery for shad in the Indian Head River that continues presently to attract large numbers of anglers. They also highlighted deficiencies at the fishway at the Elm Street Dam and recommended reconstruction with an improved design and diversion wall to improve attraction. A 4 ft Denil fishway with a diversion wall was constructed soon after their survey in 1977. No fish passage monitoring occurs at the Elm Street Dam and the passage efficiency of shad at the Elm Street Dam fishway is unknown. DMF initiated a shad electrofishing monitoring study in 2017 in order to better document the shad run and evaluate the development of an index of abundance.

Ongoing Shad Monitoring. An exploratory study was initiated by DMF in 2016 to monitor the presence and abundance of American shad in the South River and Indian Head River. Monitoring and sampling is conducted in both rivers from the head of tide to the first obstruction, using stream electroshocking to collect spawning adult shad. Biological information, including sex, size, age, and genetic samples were collected from individual shad. Scales were collected from shad to provide information on age structure, repeat spawning, mortality, and survival. Anal fin samples were collected from each shad captured and archived for future genetic research. CPUE (catch-per-unit-effort) scores (N_{Shad}/minute) from samples collected at both streams were generated as daily catch rates and used to generate mean CPUE indices. Annual mean CPUE scores were generated as indices of spawning stock abundance. Additionally, stream habitat data was collected in this monitoring effort to characterize and describe riparian and in-water features of the sampling areas in both rivers. Stream maintenance was conducted in both rivers by DMF personnel to remove obstructions to fish passage each year prior to the start of the spawning run.

Sampling trips in the South River are conducted between the last week of April through June along a 1,390 m^2 transect beginning from the South River Elementary School to the base of the Veteran's Memorial Park Dam. Annual geometric mean CPUE scores are shown in Table 2A and Figure 3A, respectively. Results indicate CPUE scores declined from 2016 to 2018 and increased from 2018 to 2020.

Male shad were dominant in samples collected in all years (mean ratio: 2:1, Table 2A). Mean size of males has declined in the five years of monitoring, and the mean size of females increased between 2016 and 2018 but decreased from 2018 to 2020. Age samples of South River shad ranged from 3 – 9 years. Mean age of males has declined in the five years of monitoring, whereas the mean age of females increased from 2016 to 2018, then decreased from 2018 to 2020. Mortality (Z) and survivorship (S) were estimated using (the Chapman-Robson method), and Z ranged between 0.7 and 2.4 (with a corresponding S ranging between 0.1 and 0.5).

Sampling trips in the Indian Head River are conducted between the first week of May through June along a 5,560 m^2 transect beginning downstream from the Elm Street Bridge to the base of the Elm Street Dam. Annual geometric mean CPUE scores are shown in Table 2B and Figure 3B, respectively. Results indicate CPUE scores increased each year throughout the monitoring period. Male shad were dominant in samples collected in all years (mean ratio: 2:1, Table 2B). Mean size of males has declined in the five years of monitoring, whereas the mean size of females was stable throughout the monitoring period despite a decrease in size in 2019. Age samples of Indian Head River shad ranged from 3-9 years. Mean age of males declined from 2016 to 2018 and increased from 2018 to 2020. Mean age of females was stable from 2016 to 2018, decreased in 2019, then increased in 2020. Mortality estimates ranged between 0.5 and 1.4 and survivorship ranged between 0.2 and 0.6.

Table 2. Annual indices of abundance, expressed as arithmetic and geometric mean catch-per-unit-effort (CPUE) scores (N_{Shad}/minute) and population demographic data collected from American shad in the (A) South River; and (B) Indian Head River.

Year	N Male	N Female	Ratio M:F	A. Mean CPUE	G. Mean CPUE	Mean TL (mm)		Mean Age		Chapman-Robson	
						Male	Female	Male	Female	Z	S
2016	44	22	2.0:1.0	0.56	0.48	489	503	6.0	5.6	0.9	0.4
2017	58	21	2.8:1.0	0.42	0.29	482	521	5.6	6.1	1.5	0.2
2018*	38	20	1.9:1.0	0.26	0.24	480	521	5.6	6.1	2.4	0.1
2019	48	32	1.5:1.0	0.45	0.39	465	497	5.3	5.6	0.7	0.5
2020	51	31	1.6:1.0	0.54	0.47	454	492	5.0	5.3	1.0	0.4

* Estimates based on low sample size

B. Indian Head River

Year	N Male	N Female	Ratio M:F	A. Mean CPUE	G. Mean CPUE	Mean TL (mm)		Mean Age		Chapman-Robson	
						Male	Female	Male	Female	Z	S
2016	62	46	1.3:1.0	0.36	0.32	488	512	5.9	6.0	1.4	0.2
2017	88	29	3.0:1.0	0.39	0.36	488	512	5.7	6.0	1.4	0.2
2018	126	55	2.3:1.0	0.48	0.43	465	512	5.2	6.1	0.5	0.6
2019	86	32	2.7:1.0	0.55	0.48	474	499	5.5	5.5	0.6	0.5
2020	77	54	1.4:1.0	0.57	0.50	473	511	5.8	5.8	0.7	0.5

Fish Ladder Specifications. A stone and concrete weir and pool fish ladder is located on the South River at the Town of Marshfield's Veteran's Memorial Park Dam. The fish ladder is approximately 21 ft. in length with 4 weirs, including an entrance weir constructed by DMF in 2017. Visual counting conducted by volunteers of the North and South River Watershed Association have observed shad presence but no passage at his location. The Elm Street Dam, located on the Indian Head River, was last rebuilt in 1920 and subsequently repaired in 1977 by the Towns of Hanover and Pembroke. A concrete Denil fishway (109 ft. length, 4 ft. width, 33 baffles) was installed to allow upstream passage.

Regulatory Authority. The owners of dams are responsible for repairing, operating, and maintaining the fish passage facilities in MA as prescribed in M.G.L. Chapter 130 §19. The Elm Street Dam is owned jointly by the Towns of Pembroke and Hanover. Following repairs by the DMF Fishway Crew at this fishway in October 2020, DMF will prepare an O&M plan to guide improved management for the location. The Veteran's Memorial Park Dam is owned by the Town of Marshfield. This fishway was improved in 2017 with the addition of a concrete entrance box. Following that work an O&M plan was prepared for the Town of Marshfield. Wetlands habitat and water quality protections are provided by M.G.L. Chapter 131 §40 and CMR Regulations 10.00 and administered *Mass*DEP.

Water Withdrawal Permissions. The Pembroke Country Club is permitted to withdraw water from the upper Indian Head River from Factory Pond downstream to Ludhams Ford (Elm Street) Dam (Subwatershed Segment MA94-04). Their present Water Management Act registration allows them to withdraw up to 0.13 MGD. The Hanover Water Department is permitted to withdraw up to 1.38 MGD in the lower Indian Head River from Ludhams Ford Dam downstream to the confluence with Herring Brook (Subwatershed Segment MA94-22, *Mass*DEP 2006.

In the South River, the Marshfield Water and Sewer Department is permitted under the Water Management Act to withdraw up to 3.30 MGD (*Mass*DEP 2006). In the North River, the Pembroke Water Department is permitted to withdraw up to 1.26 MGD and the Abington-Rockland Water Treatment Plant is permitted under the Water Management Act to withdraw up to 2.21 MGD (*Mass*DEP 2006).

Water Discharge Data: The USGS maintains one stream flow gauge in the North River watershed in Hanover at the Elm Street Bridge (No. 01105730, 3.2 km, 78.5 km^2 drainage area). The average monthly discharge at the Hanover gauge station is 105 cfs for April and 67 cfs for May from the time series record of 1966-2020.

Water Quality Monitoring: *Mass*DEP assesses waterbodies by comparing water quality to SWQC, identifying threats to habitats, and recommending remedial actions (*Mass*DEP 2007). The North River watershed was last assessed in 2001 (*Mass*DEP 2006). The upper watershed of the Indian Head River (segment MA94-04) was assessed as impaired due to metals, nutrients, and organic enrichment/low DO. The lower Indian Head River watershed (segment MA94-22) did not have sufficient information to make assessments for any designated uses (*Mass*DEP 2003). The South River watershed did not have sufficient information to make assessments for any designated uses (*Mass*DEP 2003).

ASMFC Shad Habitat Plan Framework

1.) Shad Habitat Assessment. No formal assessment of shad spawning and nursery habitat has been conducted in the North River watershed. An active restoration project is underway to consider removing the Veteran's Memorial Park Dam in Marshfield and replace it with a nature-like fishway. Fish passage improvements for shad at this location could provide access to approximately 1 km of suitable shad spawning habitat before reaching Chandlers Pond. It is uncertain if shad would pass through Chandlers Pond and continue through the small tributary feeding into the pond. No project presently is ongoing to evaluate the removal of the Elm Street Dam on the Indian Head River. Such a project would certainly provide benefits to shad passage and access to increased spawning habitat. There is 4-5 km of potentially suitable shad spawning and nursery habitat between the Elm Street Dam and the next dam at Forge Pond in Hanson. This dam is presently impassible with legacy concerns over industrial sediments. Access to Forge Pond dam would also require bridge riprap modifications at Cross Street.

2.) Threats Assessment. No formal threat assessments have been made for shad in the North River. This river system contains the largest remaining shad populations in coastal MA rivers and supports ongoing sportfisheries. Two dams appear to limit upstream access for shad in the Indian Head and South rivers. Therefore, **Barriers to Migration** are an ongoing threat to shad in this river system. However, these dams have been in place for centuries and anecdotal reports suggest higher shad fishery catch and participation in the 1960s and 1970s. It is likely that other threats are influential to the status of these two small shad runs. Increasing groundwater and surface **Water Withdrawal** as these coastal towns have been further developed in recent decades could be limiting surface flow and habitat quality in the rivers. This threat has not been assessed. The South River has experienced significant encroachment of wetland plants into the river channel between the Veteran's Memorial Park Dam and Chandler Pond in recent decades. This process has led to the deposition of large amounts of fine sediments and reduced channel definition in this river stretch.

3.) Habitat Restoration Plan. Currently, DMF does not have an ongoing project or imminent plans to initiate an assessment of the two North River shad run or conduct a habitat restoration plan. Two areas of interest are a shad spawning and nursery habitat assessment in both the Indian Head and South rivers. DMF will look for cooperative opportunities to pursue shad habitat assessments in this watershed with a priority given to the Indian Head River upstream of the Elm Street Dam. The DMF Diadromous Fish Habitat Restoration Priority List has the Cross Street Bridge location ranked 1st among 82 possible projects in the South Shore Coastal Drainage Area. This project would benefit shad if passage were improved at the Elm Street Dam. DMF staff will prioritize the initiation of an evaluation of this fish passage improvement project as opportunities occur. DMF drafted a South River Stream Maintenance Plan for the Town Marshfield in 2016 and has worked with Town staff and volunteers on numerous trips to remove debris jams and shrub overgrowth upstream of Veteran's Memorial Park Dam. This work revealed significant alteration of potential shad spawning pool and riffle habitat as wetland shrub plants choked the river channel and led to high sediment accumulation and channel braiding.

Agency or Agencies with Regulatory Authority. Massachusetts DMF coastal waters diadromous fish, *MassWildlife* inland waters diadromous fish, and *Mass*DEP - wetlands and water quality protection.

Action actively being addressed by agency. Fishway repairs were conducted by DMF at the Elm Street Dam on the Indian Head River in 2020, and stream maintenance is ongoing in the South River. DMF intends to continue with the shad electrofishing project in both rivers and look for opportunities to evaluate the potential shad habitat upstream of the Elm Street Dam in the Indian Head River.

Timeline and Costs for Achieving Goals/Targets. None established. Funding is not presently available.

Other organizations. The North and South River Watershed Association has been actively involved in natural resource stewardship in this watershed for decades. This association is interested in participating in diadromous fish habitat and population monitoring that could benefit shad. The Towns of Pembroke, Hanover and Marshfield have demonstrated similar interests and stewardship.

Neponset River

Watershed Information. The Neponset River originates at the Neponset Reservoir in Foxboro and flows for 45 km to Dorchester Bay (Figure 4). Fish passage is obstructed at the Lower Mills Dam (also called the Baker Chocolate Factory Dam) located at head-of-tide (6.8 rkm) on the Dorchester and Milton border. The Lower Mills Dam has a 7 ft spillway height and 79 ft spillway width that is connected to former mill buildings on both sides. The next dam upstream is the Tilestone and Hollingsworth Paper Company Dam at 11 rkm. This dam has a 9.5 ft spillway height, 151 ft spillway length with no fish passage facilities. DMF conducted a survey upstream of the two dams in 1995 and documented 25.3 km of suitable riverine habitat for shad and river herring spawning.

American Shad Status. Reback and DiCarlo (1972) recognized a substantial former shad fishery in the Neponset River that was eliminated by two dams in the lower watershed and launched efforts to restore passage in the 1990s. In anticipation of fish passage improvements at the two dams, DMF stocked 1,047 gravid adult shad from 1995 to 2001. Extensive multi-agency efforts have investigated dam removal and fishway options at the dams since 1994. Unfortunately, costly remediation of industrial contaminants has slowed momentum on the process: stalling what might be the shad restoration concept with the highest potential benefits among coastal MA rivers. Actual records on the recent presence of shad are limited. DMF monitoring for smelt spawning below the spillway of the Lower Mills Dam observed a few adult shad during late spring on several dates in the 1980s and 1990s.

Regulatory Authority. The owners of dams are responsible for repairing, operating, and maintaining the fish passage facilities in MA as prescribed in M.G.L. Chapter 130 §19. Both dams are owned by the MA Department of Conservation and Recreation (DCR). Wetlands habitat and water quality protections are provided by M.G.L. Chapter 131 §40 and CMR 10.00 and administered by *Mass*DEP.

Water Withdrawal Permissions. Several minor water withdrawals occur in the Neponset River watershed. However, municipal water supply for towns in the watershed is primarily provided by the Massachusetts Water Resource Authority, independent of the Neponset River.

Water Discharge Data. The USGS maintains a stream flow gauge in the Neponset River watershed in Milton at the Baker Dam (No. 011055566, 6.8 rkm, 262 km^2 drainage area). Flow data at this station is adjusted to account for tidal influence. The average monthly discharge at the Baker Dam gauge station is 580 cfs for April and 337 cfs for May from the time series record of 1996-2020.

Water Quality Monitoring. *Mass*DEP assesses waterbodies by comparing water quality to Surface Water Quality Standards (SWQC), identifying threats to habitats, and recommending remedial actions (*Mass*DEP 2007). The Neponset River watershed was last assessed during 2004; with a large percentage of the potential shad habitat listed as *Impaired* due to several stressors including low dissolved oxygen, very high levels of polychlorinated biphenyls (PCBs), and high nutrients.

ASMFC Shad Habitat Plan Framework

1.) Shad Habitat Assessment. A shad habitat assessment was conducted in the Neponset River during 1995 by DMF. This assessment found suitable habitat for shad and prompted restoration efforts in the watershed that have stalled due to concerns over project costs and contaminated sediments. The DMF Diadromous Fish Habitat Restoration Priority List has the Lower Mills location ranked 3rd (tied) among 111 possible projects in the Boston Harbor and North Shore region. Shad restoration potential is an important factor that contributes to this high rank as a restoration priority.

2.) Threats Assessment. No formal threat assessments have been made for shad in the Neponset River watershed. The primary threat is clearly **Barriers to Migration** given the two impassible dams in the lower watershed. Water flow does not appear to be a major threat given the stream flow gauge records of relatively high flow for the entire shad spawning and nursery habitat period. Sea level rise could be a factor in this watershed as evidence of higher tidal influence at Lower Mills has been observed during more than 30 years of DMF monitoring. The rising sea level could be a significant negative influence on rainbow smelt spawning habitat and other head-of-tide spawning fish. This impact likely does not influence shad; however, the impact to other species adds to the rational for providing fish passage at Lower Mills.

3.) Habitat Restoration Plan. Currently, DMF does not have an ongoing project or imminent plans to initiate an assessment of the Neponset River shad run or conduct a habitat restoration plan. The results of the prior survey are likely still relevant, although updated information may benefit restoration goals. No funding is presently available for shad restoration planning or population monitoring.

Agency or Agencies with Regulatory Authority. Massachusetts DMF - coastal waters diadromous fish, *MassWildlife* - inland waters diadromous fish, and *Mass*DEP - wetlands and water quality protection.

Action actively being addressed by agency. None at the present time. In 2018 the dam owners, DCR, signaled some willingness to re-examine providing passage at the Baker Chocolate and Tilestone Dams. DMF intends to revisit the concept of fish passage improvements at the two dams at the next opportunity with DCR.

Timeline and Costs for Achieving Goals/Targets. None established. Funding is not presently available.

Other organizations. The Neponset River Watershed Association has been actively involved in natural resource stewardship in the Neponset River for decades. This association is interested in participating in diadromous fish habitat and population monitoring that could benefit shad. The DCR as dam owners, will be an essential partner in any restoration planning.

Charles River

Watershed Information: The Charles River is a relatively large coastal river in Massachusetts that provides habitat for diadromous fish for nearly 130 km as it flows to Boston Harbor (Figure 4) and borders the lands of 24 towns and cities. The drainage area of the primarily urbanized watershed is approximately 805 km^2. There are eight dams that fragment diadromous fish habitat in the Charles River. The upper two dams have no passageways and the lower six have passageways with most designed to pass shad but with unknown efficiency.

American Shad Status: Belding (1921) refers to the Charles River as one of the first rivers in Massachusetts to lose its shad and alewife fisheries due to pollution and dams. Reback and DiCarlo (1972) state that shad were not present in the Charles River at the time of their 1960s survey of anadromous fish; however, they note the high restoration potential and interest of DMF to pursue shad restoration. A river assessment was conducted by DMF in the late 1960s to determine the available potential spawning habitat. The survey covered a total of 98 rkm from the Charles River locks to Medway and documented approximately 64 rkm with suitable shad spawning habitat. This survey led to an effort to stock fertilized shad eggs in 1971. Intensive stocking of shad eggs occurred through much of the 1970s and sporadic stocking of mature adult shad continued from 1978 to 1992. The results of the stocking effort were not evaluated, although returning adult shad were captured in low numbers while collecting river herring for stocking below the Watertown Dam during the 1990s and 2000s (Reback et al. 2005). Shad stocking efforts were renewed in 2006 to apply improved culture techniques and oxytetracycline (OTC) marking to evaluate restoration responses.

Ongoing Shad Monitoring

Starting in 2006, a cooperative effort between DMF and the USFWS has made several concerted efforts to restore American shad to the Charles River. Restoration efforts have included stocking larvae into potential nursery habitat upstream of barriers, video monitoring of fishway passage, telemetry studies, and age validation work.

From 2006 – 2017, USFWS stocked an average of 2.2 million OTC-marked larvae in potential nursery habitat upstream of the Moody Street Dam (4th barrier). Gravid American shad were collected from the Merrimack River and cultured to fry stage at the USFWS Nashua or North Attleboro hatcheries. Starting in 2012, the two agencies conducted electrofishing downstream of the Watertown Dam (2nd barrier) in document the status of the shad run and restoration contributions. During 2012, weekly, spawning run electrofishing trips yielded a total of 30 adult shad. The otoliths of each adult were removed and examined for an OTC mark and were aged along with scales from each fish. Of the 30 adults retained, 25 were an age (3-6) that could have originated from the restoration efforts. Of those 25 fish, 15 possessed an OTC mark. It is unknown whether non-marked fish are the result of straying, hatchery product that lost or failed to incorporate an OTC mark, or remnant of a natural population. Since the resumption of stocking in 2006 an effort was made to identify if a remnant spawning run existed, using the Denil fishway at the Watertown Dam as a fish trap.

When the trap was operated, adult shad were prevented from passing through the upstream exit by way of tightly spaced vertical bars. The trapping approach had limitations, although did document the presence of low numbers of adult shad. In 2013 and 2014, DMF replaced this trap methodology with a video monitoring system. Video data documented over 350,000 river herring and 44 adult shad passing through the fishway in 2013 and over 310,000 river herring and 41 shad in 2014. In 2013 and 2014 only 58 (2013: 22, 2014: 36) adult American shad were captured while electrofishing, meaning the number of shad successfully utilizing the fishway exceeded the number sampled below and supports the possibility of natural reproduction occurring in the watershed. However, most shad on video appeared smaller and were likely males. The entrance of the Watertown Dam fishway is on the opposite side of the river from the thalweg, creating an attraction problem for shad. Shad would need to leave the thalweg well downstream of the fishway and follow flow on the river right bank or cross from the thalweg below the dam apron to river right over a large, shallow and turbulent area.

From 2008 to 2016 larval American shad reared in the USFWS North Attleboro National Fish Hatchery and stocked to the Charles River received oxytetracycline (OTC) marks. The initial years of marking were to help differentiate between natural and stocked American shad. This program was modified to incorporate an age validation that began in 2013. Limited age validation work has occurred for this species and additional studies in different watersheds will benefit coastwide management. Examination of larvae sacrificed to evaluate marking procedures indicated that OTC marks were present in most individuals but that larvae appeared to incorporate OTC better, leading to stronger marks, at older ages. Beginning in 2013, larvae received double or triple marks with varying days between marks. Variation of mark procedures between years allows marked fish to be assigned to a specific hatch year, thereby allowing for direct age validation. Recaptures of multiple marked fish began in 2017 but catches of marked shad were low until 2019 (2017 N = 17, 2018 N = 24, 2019 N = 32). Given the small sample sizes and the fact that counting daily growth rings can be difficult, there was some uncertainty in year class identification in samples from 2017 and 2018. The larger sample size and the increased abundance of triple marked samples in 2019 has increased our confidence that we can correctly identify year classes and validate our ages. Due to COVID related field work restrictions no sampling occurred in 2020.

In the springs of 2015 and 2016, DMF collaborated with USFWS Central New England Fisheries Conservation Office biologists to conduct an acoustic telemetry study on spawning adult shad. The goals of the study were to examine impediments to passage and restoration by understanding distribution of adult shad in the Charles River (Gahagan and Bailey 2020). A total of 98 adult American shad were tagged and acoustic arrays were maintained during 2015-2017. The study successfully used surgical implantation methods to track American shad over multiple years and achieved other study goals.

Fish Ladder Specifications: Detailed specifications on the Charles River fishways are provided in Reback et al. (2005). The first barrier in Boston Harbor is the Charles River Locks, built for navigation and flood control. A locking protocol is used to pass migrating fish at this location with specific timing provisions for the shad migration. The 2nd, 5th and 6th dams have large-width (4-6 ft) Denil fishways designed by the USFWS to pass river herring and shad. The 3rd barrier has been partially breached to allow fish passage. The 4th barrier at the Moody Street Dam is a hybrid ladder with a lower section of 4' Denil baffles leading to a large weir pool section with a 180° turn between the 2nd and 3rd weirs. The uppermost dams, the Metropolitan Circular Dam at 32.2 rkm and the Silk Mill Dam at 32.5 rkm have no fishways. Shad presently have access to approximately 32 rkm of potentially suitable habitat.

Regulatory Authority: The owner of the dam is responsible for repairing, operating, and maintaining the fish passage facilities as prescribed in M.G.L. Chapter 130 §19. Seven of the eight dams on the Charles River are owned by the Massachusetts Department of Conservation and Recreation. The Silk Mill Dam is privately owned. Wetlands habitat and water quality protections are provided by M.G.L. Chapter 131 §40 and CMR 10.00 and administered by the *Mass*DEP.

Water Withdrawal Permissions: With a large urban watershed that connects many towns, the Charles River is subject to complex water management. Communities in the metropolitan Boston area (inside Route 128) receive water from the Massachusetts Water Resources Authority's Quabbin Reservoir. Communities outside of Route 128 are allowed under 14 MA Water Management Act permits to withdraw water from groundwater wells and reservoirs.

Water Discharge Data: The importance of the Charles River for water resource management is reflected by the presence of 18 USGS stream flow gauges in the watershed. The Waltham stream flow gauge station (No. 01104500, 19.6 rkm, 650 km^2 drainage area) is on the main stem Charles River and is most proximate to the fishways. The average monthly discharge at the Waltham gauge station is 616 cfs for April and 366 cfs for May from the time series record of 1931-2020.

Water Quality Monitoring: *Mass*DEP assesses waterbodies by comparing water quality to Surface Water Quality Standards, indentifying threats to habitats and recommending remedial actions (*Mass*DEP 2007). The Charles River watershed was last assessed during 2002-2006 (*Mass*DEP 2008); with a large percentage of the potential shad habitat listed as *Impaired* due to several stressors including low dissolved oxygen, high nutrients, and invasive plant growth.

ASMFC Shad Habitat Plan Framework

1.) Shad Habitat Assessment. No formal assessment of shad spawning and nursery habitat has been conducted in the Charles River watershed since the late 1960s. The interest of maintaining shad passage in the Charles River has a long history that includes the installation of four large Denil fishways at dams that were designed for shad passage. Shad presently have access to approximately 32 rkm of potentially suitable habitat. There are no present plans to update Charles River shad habitat assessment plans. Should opportunities arise to consider updates on shad habitat information in the Charles River the river upstream of the impassible Metropolitan Circular and Silk Mill dams should be evaluated.

2.) Threats Assessment. No formal threat assessments have been made for shad in the Charles River.
Historical **Barriers to Migration** and degraded water quality were identified in past DMF surveys as impacting shad in the Charles River. Much work was conducted to provide fish passage at 6 of the 8 dams during the 1970s and 1980s. The implementation of the Clean Water Act in the 1970s slowly reduced industrial pollution loads in the river. Presently, Barriers to Migration remains a significant threat due to inefficiencies at some of the fish passage facilities and the two remaining impassible dams. To this point, the results of the recent telemetry study showed that the New Boston Dam at the head of

tide and the Watertown Dam, the first obstruction within the freshwater segment of the river, both lead to migratory delays and likely cause additive mortality (Gahagan and Bailey 2020). New Boston Dam delayed pre- and post-spawn shad, with several post-spawn shad dying at the dam and lock structures. The Watertown Dam blocked most pre-spawn shad from ascending the river and fish that did pass experienced delays of multiple days.

The watershed is heavily urbanized with documented surface water quality and stormwater impairments. Stormwater is a concern as rain events quickly degraded water quality in the watershed. Invasive plant species are also a threat of concern; particularly water chestnut.

3.) Habitat Restoration Plan. Currently, DMF does not have an ongoing project to initiate a shad restoration plan in the Charles River watershed. We **recommend** the following actions for the Charles River as opportunities allow: (1) assessment of the amount and suitability of Charles River habitat for shad spawning and rearing; (2) further assessment of the passage efficiency at the Watertown Dam fishway and the Moody Street Dam; (3) evaluate the feasibility of providing fish passage at the two upstream impassible dams; (4) In coordination with MA DCR, prepare Fishway Operation and Maintenance Plans for the four upstream fishways at DCR dams with consideration for shad passage requirements; and (5) evaluate the feasibility of fish passage improvements through removal of the Watertown Dam. The Watertown Dam project is the top ranked location among 111 possible projects in the DMF Diadromous Fish Habitat Restoration Priority List for the Boston Harbor and North Shore region (Version-4, 2020). In 2018-2019, DMF participated in a Feasibility Study to examine the removal of the Watertown Dam. The study has not been finalized but the results suggest removal is a feasible option for improving fish passage. The impassible Metropolitan Circular Dam and Silk Mill Dam are tied for 15th on the DMF Diadromous Fish Habitat Restoration Priority List for the Boston Harbor and North Shore region. If passage were provided at these two dams an additional 32 rkm (per survey of 1969-1970) of potential shad spawning habitat could be gained.

Agency or Agencies with Regulatory Authority. Massachusetts DMF- coastal waters diadromous fish, *MassWildlife* - inland waters diadromous fish, and *Mass*DEP - wetlands and water quality protection.

Action actively being addressed by agency. Present activities included fishway O&M coordination with MA DCR, and an ongoing multi-agency dam removal feasibility study for the Watertown Dam.

Initial Habitat Goal. None established. Funding is not presently available.

Timeline and Costs for Achieving Goals/Targets. None established. Funding is not presently available.

Other organizations: DMF conducts most field work in cooperation with the USFWS and *MassWildlife*. The Charles River Watershed Association is also engaged in a wide range of activities to monitor and improve the aquatic life of the Charles River.

Related Activities

The following three ongoing DMF projects related to diadromous fish could benefit the interest of improving our knowledge of American shad habitat in the future:

1.) A DMF coast-wide anadromous fish passage survey was conducted in the early 2000s (Reback et al. 2005) with a focus on river herring and structural fishways. The datafile of this survey was used to prepare a DMF Diadromous Fish Habitat Restoration Priority List in 2008 with the same focus on river herring and structural fishways. The DMF priority list was updated in 2011, 2016 and 2020 (V-4) with increasing inclusion of information on other diadromous fish species and other habitat types. This datalayer can be improved in the future by adding shad habitat data. Additionally, plans are underway to update the coast-wide anadromous fish passage survey in 2021. This activity can also include more attention to shad spawning, nursery and migratory habitat.

2.) A GIS datalayer of diadromous fish habitat was developed in cooperation with the Massachusetts Department of Transportation in 2013 to provide tools for transportation and diadromous fish restoration planning. The GIS datalayer was focused on river herring migrations and depended on site information and species presence/absence information largely provided by the DMF coast-wide survey (Reback et al. 2005) and DMF Diadromous Fish Habitat Restoration Priority List. The GIS datalayer was updated in 2018 and included an expansion of information on additional diadromous fish species. The datalayer was updated again in 2020 with the objective to increase information on other species and habitat types. This datalayer can be improved in the future by adding shad habitat data.

3.) The DMF conducts habitat assessments for rainbow smelt and river herring to under a Quality Assurance Program Plan (QAPP) that relates habitat and water quality conditions to aquatic life and species life history thresholds (Chase 2010). The QAPP provides guidance that can be transferable to riverine shad habitat assessments and could be updated in the future to include Specific Operation Plans for shad habitat assessments.

Citations

Belding, D.L. 1921. A report upon the alewife fisheries of Massachusetts. Mass. Div. of Fish. and Game, Dept. of Natural Resources, 135 pp.

Chase, B.C. 2010. Quality Assurance Program Plan (QAPP) for Water Quality Measurements Conducted for Diadromous Fish Habitat Monitoring. Version 1.0, 2008-2012. Mass. Div. of Mar. Fish., Tech. Report No. TR-42. http://www.mass.gov/dfwele/dmf/publications/tr42.pdf

Chase, B.C., A. Mansfield, and P. DuBois. 2013. River herring spawning and nursery habitat assessment - Silver Lake, 2008-2009. Mass. Division of Marine Fisheries, Tech. Rep. Series, TR-54.

CRASC. 1992. A management plan for American shad in the Connecticut River Basin. Connecticut River Atlantic Salmon Commission, Sunderland, MA.

CRASC. 2014. American shad Habitat Plan for the Connecticut River. *Prepared for* the Atlantic States Marine Fisheries Commission *by* the Connecticut River Atlantic Salmon Commission, Sunderland, MA.

Gahagan, B.I. and M.B. Bailey. 2020. Surgical implantation of acoustic tags in American shad to resolve riverine and marine restoration challenges. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 12(5): 272-289.

Gomez and Sullivan, 2013. Forge Pond Dam Fish Passage Improvement Feasibility Study and Preliminary Design. Prepared *for* Mass. Division of Marine Fisheries *by* Gomez and Sullivan Engineers, P.C., Henniker, NH.

Greene, K.E., J.L. Zimmerman, R.W. Laney, and J.C. Thomas-Blate. 2009. Atlantic coast diadromous fish habitat: a review of utilization, threats, recommendations for conservation, and research needs. Atlantic States Marine Fisheries Commission Habitat Management Series No. 9, Washington, D.C.

Rojko, A.M., S.D. Tamul, and L.E. Kennedy. 2005. Taunton River Watershed Water Quality Assessment Report. Mass. Dept. of Environmental. Protection, Div. of Watershed Mgt ., Worcester, MA, Rep. No. 62-AC-1.

MA DMF. 2014. American Shad Habitat Plan for Massachusetts Coastal River. Submitted to the Atlantic States Marine Fisheries Commission. Approved Feb. 6, 2014.

MassDEP. 2003. *Final Massachusetts Year 2002 Integrated List of Waters.* Massachusetts Department of Environmental Protection, Division of Watershed Management, Worcester, MA. Document CN 125, Final September 2003.

*Mass*DEP. 2006. South Shore Coastal Watersheds 2001 Water Quality Assessment Report. Report No. 94-AC-2. Mass. Dept. of Environ. Protection, Division of Water Management, Worcester, MA.

*Mass*DEP. 2007. Massachusetts Surface Water Quality Standards. Mass. Dept. of Environ. Protection, Division of Water Pollution Control, Technical Services Branch, Westborough, MA (Revision of 314 CMR 4.00, January 2007).

*Mass*DEP. 2008. Charles River 2002-2006 Watershed Water Quality Assessment Report. Mass. Dept. of Environmental. Protection, Div. of Watershed Mgt., Worcester, MA Rep., No. 72-AC-4.

*Mass*DEP. 2009. Narragansett and Mount Hope Bay Watersheds 2004-2008 Water Quality Assessment Report. Mass. Dept. of Environmental. Protection., Div. of Water. Mgt., Worcester, MA, Rep. No.61/53-AC-2.

MRTC. 1997. Strategic plan and status review: anadromous fish restoration program, Merrimack River. Merrimack River Technical Committee, U.S. Fish and Wildlife Service, Nashua, New Hampshire.

MRTC. 2010. A Plan for the restoration of American shad in the Merrimack River Watershed. Merrimack River Technical Committee, U.S. Fish and Wildlife Service, Nashua, New Hampshire.

Reback, K. E. and J. S. DiCarlo. 1972. Completion report on the anadromous fish project. Mass. Div. Mar. Fish., Publication No. 6496, 113 pp.

Reback. K.E., Brady, P.D., McLaughlin, K.D., and Milliken, C.G. 2004. A survey of anadromous fish passage in coastal Massachusetts: Part 1. Southeastern Massachusetts. Mass. Div. Mar. Fish. Tech. Report No. TR-15.

Reback, K.E., P.D. Brady, K.D. McLauglin, and C.G. Milliken. 2005. A survey of anadromous fish passage in coastal Massachusetts: Part 4. Boston and North Coastal. Mass. Div. of Mar. Fish., Tech. Report No. TR-18.

Turner, S. *in Prep.* River herring spawning and nursery habitat assessment - Shad Factory Pond and the Palmer River. Mass. Div. Mar. Fish. Tech. Report.

Figure 1. Palmer River and Taunton River in the Narragansett Bay Watershed. The green dots are dams that are passable to migratory fish, the red dots are impassible dams, and the yellow dots indicate improvements are recommended.

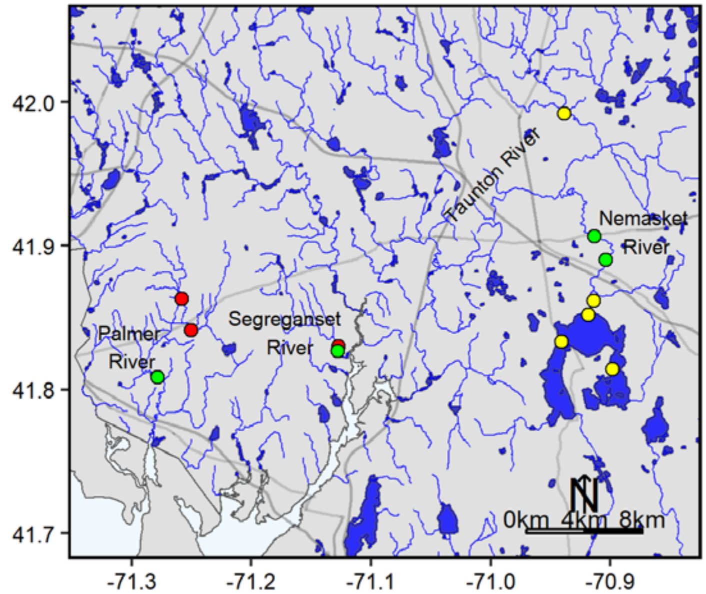


Figure 2. Jones River and North River watersheds in the South Shore Coastal Drainage Area. The green dots are dams that are passable to migratory fish, the red dots are impassible dams, and the yellow dots indicate improvements are recommended. The Indian Head River Dam is located at the green dot west of the North River title.

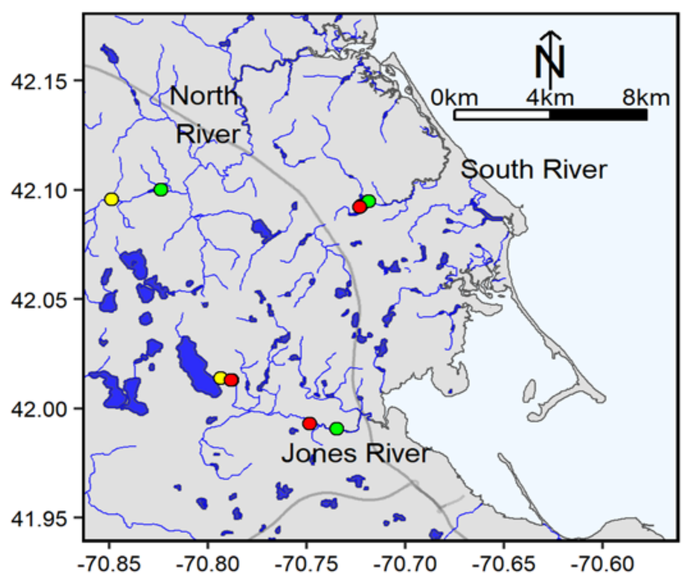
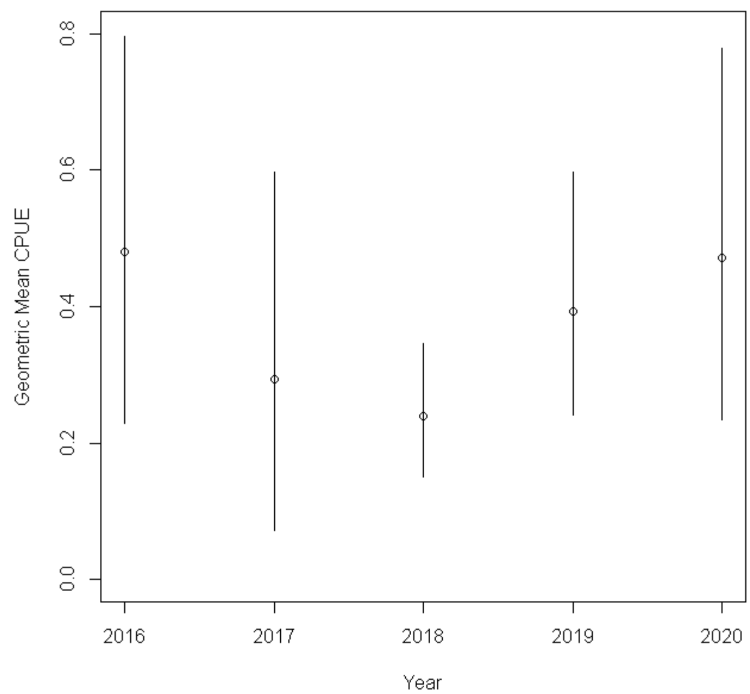


Figure 3. Annual Geometric Mean CPUE scores (+/- 95% C.I.) of American shad (N_{Shad}/minute) derived from electrofishing surveys conducted in the (A) South River; and (B) Indianhead River.

A. South



B. Indian Head

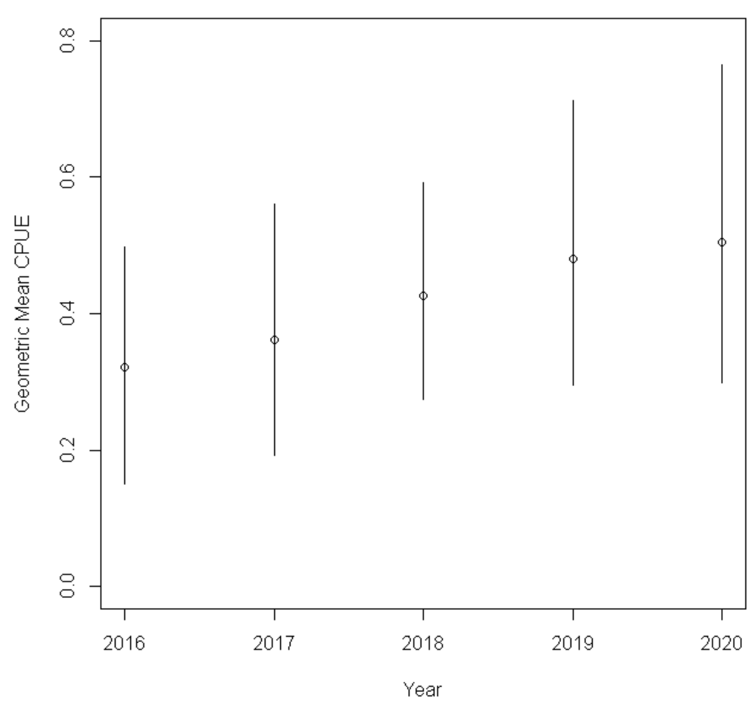
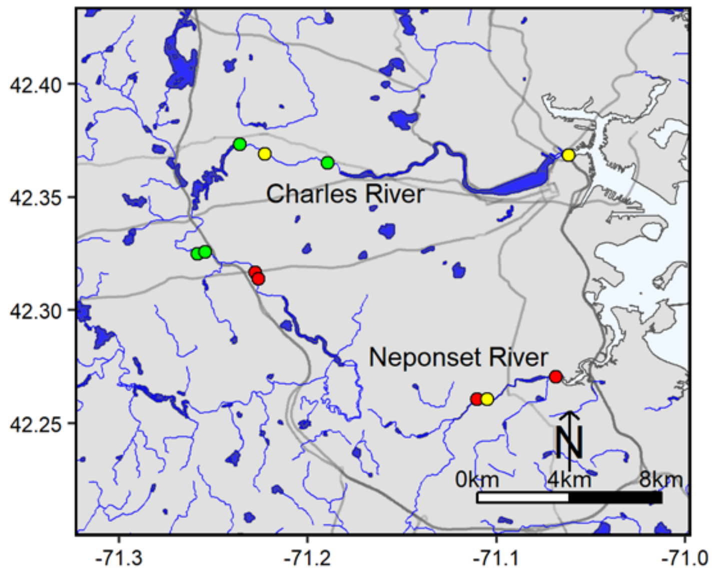
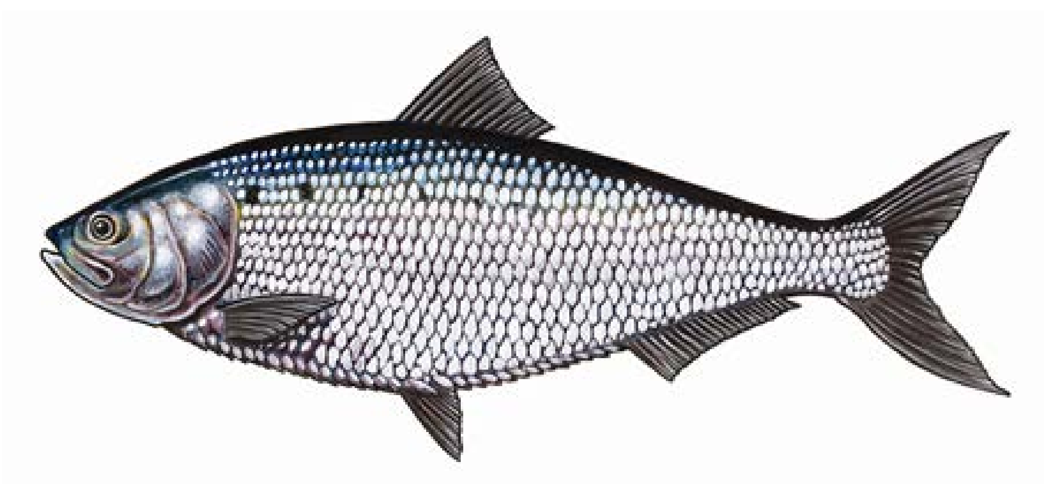


Figure 4. Charles River and Neponset River in the Boston Harbor Watershed. The green dots are dams that are passable to migratory fish, the red dots are impassible dams, and the yellow dots indicate improvements are recommended.



Rhode Island American Shad Habitat Plan

Submitted to the
Atlantic States Marine Fisheries Commission



Prepared by Patrick McGee & Phil Edwards
RI DEM Fish & Wildlife

January 2021

Rhode Island American Shad Fisheries Management Plan
Pawcatuck and Pawtuxet Rivers

Overview

Report submitted by the Rhode Island Department of Environmental Management, Division of Fish & Wildlife. This report provides river-specific information for the two known American shad runs in the state of Rhode Island, the Pawcatuck River and the Pawtuxet River. American shad restoration is an ongoing effort by the Division and its many partners. The Division continues to try to improve shad passage efficacy on these systems, while also seeking to expand passage to additional systems deemed to have the potential to provide suitable American shad habitat.

The 2020 Atlantic States Marine Fisheries Commission's American Shad Stock Assessment and Peer Review Report provides an extensive review of available literature and discussion on the topic of fish passage (ASMFC 2020). Specifically, it highlights the issues with lack of evaluation and performance from decades-old approaches, facilities designs/operations that are not effective, and therefore cannot reasonably be expected to achieve management and restoration goals without significant changes. The Assessment Report also provides an important quantitative modeling approach examining shad habitat and passage barriers, and the need to address status quo fish passage performance. The impacts of these barriers and status quo passage are described and also modeled as effects on spawner population size under three scenarios, 1) no barriers, 2) first barrier with no passage, and 3) realistic fish passage performance measures applied to barriers (e.g., upstream passage efficiency of 50%).

The Assessment Report used standardized data and modelling approaches that quantified the impacts of barriers and fish passage as significant in all three management areas examined based on shad life history and habitat (New England, Mid-Atlantic, and South Atlantic). The assessment determined that overall, dams completely or partly block nearly 40% of the total habitat once used by American Shad. The model results of the "no barriers" scenario yielded an estimated spawner production potential 1.7 times greater than that yielded by the scenario assuming no passage at the first barrier: 72.8 million versus 42.8 million fish. The results of the third model scenario, which applies "realistic" (i.e., current) fish passage efficiencies, resulted in a gain of less than 3 million fish. Conclusions include "losses in (spawner production) potential are significant in each state and region." The Assessment Report provides a strong justification for the need and benefits of requiring improved fish passage performance measures. Additionally, meeting such improved passage performance standards is now an achievable goal given the current state of knowledge on fish behavior, swimming performance, and fish passage engineering expertise.

Habitat Assessment: Pawcatuck River

Since the 1970s, RIDEM has accomplished substantial progress in the restoration of diadromous fish to the 308-mi^2 Pawcatuck River watershed. RIDEM has been successful to date at re-establishing low-levels of self-sustaining American shad and river herring populations in the lower reach of the Pawcatuck River watershed. This work has included installation of structural fishways (1970s), limited structural fishway improvements, broodstock enhancement, fry stocking programs and monitoring of both adult returns and juvenile recruitment (e.g., fish trap counts, juvenile seine surveys, electrofishing, and radio telemetry). Although the Pawcatuck River has historic diadromous fish runs, each of the lower three dams (White Rock, Potter Hill, and Bradford) and poorly functioning structural fishways greatly reduced the passage efficiency of anadromous fish from accessing valuable spawning and nursery habitat. Starting in 2013, the State of Rhode Island Department of Environmental Management (RIDEM), Division of Fish and Wildlife (DF&W) committed funds and initiated a process to assess specific passage problems (via U.S. Army Corps of Engineers (ACOE) Section 22 of the Water Resources Development Act) to document passage deficiencies and passage restoration alternatives at each of the first three dams on the Lower Pawcatuck River. In 2015 partners began completing fish passage improvements at the lower three dams utilizing a multi-million dollar USFWS Sandy Flood Resiliency funds and other sources to remove the White Rock Dam, improve the Potter Hill Fishway and construct a rock ramp fishway at the Bradford Dam.

Since 2010, there has been a substantial effort to improve fish passage at the dams located upstream of the three dams described above that are on the lower portion of the Pawcatuck River. This three phase upper Pawcatuck River fish passage restoration project was awarded a multi-million dollar NOAA American Recovery and Reinvestment Act and involves numerous funding and project partners. The first of the three-phase project was the 2010 removal of the Lower Shannock Falls which included the installation of rock weirs and bank stabilization. In 2012, a Denil fishway and state-of-the-art eel pass was constructed at the Horseshoe Falls Dam and in 2013 a rock ramp fishway was completed at the sixth obstruction-Kenyon Mill Dam. The fish passage restoration improvements at the first three fishways complemented the new fish passage restoration projects completed on the upper Pawcatuck River watershed. Currently DFW and partners are looking at fishway options to enhance fish passage at a small USGS gauging station located at the Cronan fishing area. The dam is passable at certain flows, but improvements will enhance fish passage.

The six fish passage projects described below will enhance diadromous fish passage to over 22 miles of the main stem Pawcatuck River, 48 miles of tributaries, and access to over 1,967 acres of ponds providing critical spawning and rearing habitat. The goal is to improve river connectivity for target fish species and provide passage between Little Narragansett Bay and the high-quality waters of upper Pawcatuck River. An increase in abundance of the target diadromous species, to be monitored and documented by RIDEM and partners over time, will ultimately serve as the metrics for performance of the proposed restoration projects. The long-term goal of the project is to restore self-sustaining populations of anadromous and catadromous fish species. The unimpeded access to riverine and lacustrine habitats is expected to potentially result in an annual shad run in the thousands and river herring runs in the hundreds of thousands in the watershed. In addition, RIDEM, USFWS, USGS, URI and other partners initiated a two-year telemetry study in 2018 for shad and herring on the mainstem Pawcatuck River at each of the main fishways. Preliminary results show where radio tagged fish migrated to along the river and areas where migration delays may be occurring. The information will assist in prioritizing sites for fish passage improvements. Final fish telemetry results from the study are expected in 2020/2021.

Threats Assessment: Pawcatuck River

Barriers to Migration

Description:
Each of the three lowermost dams on the Pawcatuck River had a bypass system (breached canal and fish ladders) to provide fish passage for diadromous fish species including river herring and American shad. However, at each of these dams were known and documented problems with the bypass systems that could impact fish passage efficiency. The State of Rhode Island Department of Environmental Management, Division of Fish and Wildlife partnered and requested that the US Army Corps of Engineers (ACOE) provide planning assistance (Section 22 of the Water Resources Development Act of 1974) to determine the fish passage efficiency for species of diadromous fish at the three dam sites located on the lower Pawcatuck River in 2013. The study produced a detailed report that identified and documented the current conditions at each of the sites and determined the impact these conditions had on fish passage. Recommendations and preliminary plans for improving fish passage efficiency at each site were included in the report.

Action 1) White Rock Dam Removal

Description of Work: The study evaluated the White Rock Dam by-pass channel, which previously allowed for fish passage but had water flows at the existing dam which may have attracted anadromous fish towards a dead-end channel. The report revealed that even at adequate flows, the by-pass was inefficient at passing anadromous fish, and partners worked to remove the dam and restore the original river channel utilizing USFWS Sandy Resiliency Funds and other sources.

Agencies: Feasibility study by RIDEM, ACOE, TNC and WPWA.
Dam Removal-The Nature Conservancy (TNC) and USFWS, RIDEM, CTDEEP, WPWA, USACOE, CRMC, Griswold Textile, Fuss and O'Neil, Sumco and others.

Timeline/Progress: Report completion date 2013. Dam removal completed Fall 2015.

Action 2) Potter Hill Fishway Improvements

Description of Work: The feasibility study determined the fish passage efficiency of the 1970's constructed Potter Hill Denil fishway with current dam and false attraction flow conditions was poor. RIDEM and partners changed the baffles to decrease water velocities and improved the entrance channel utilizing a long-armed excavator.

Agencies: TNC, USFWS, RIDEM, US ACOE, TNC, WPWA and others.

Timeline/Progress: Completed October 2016

Action 3) Bradford Dam Rock Ramp Fishway

Description of Work: The feasibility study determined the fish passage efficiency of the 1970's Denil fishway with new modifications and current dam conditions was poor with numerous false attraction flow conditions. Recent modifications were made to the Bradford fishway to enhance American shad passage. Modifications included an extended fishway entrance and a decrease in the slope at the lower fishway section in 2008. The study determined the fishway was still inefficient to migratory fish and the best option was a rock ramp fishway funded by USFWS Sandy Resiliency Funds and other sources. The rock ramp fishway features a series of pools, constructed of natural stone weirs to facilitate fish passage.

Agencies: Feasibility study by RIDEM, ACOE, TNC and WPWA. Fishway modifications in 2008 by numerous partners. Rock Ramp in 2018 -TNC and USFWS, RIDEM, CTDEEP, WPWA, USACOE, CRMC, Bradford Dye, Fuss and O'Neil, Sumco and others.

Timeline/Progress: First fishway modifications completed 2008, Report 2013, Rock Ramp March 2018.

Action 4) Lower Shannock Falls Dam Removal

Description of Work: There has been a substantial effort to improve fish passage at dams located upstream of the three dams described above that are on the lower portion of the Pawcatuck River. This three phase upper Pawcatuck River fish passage restoration project was awarded a multi-million dollar NOAA American Recovery and Reinvestment Act grant due to its high level of restoration priority. The first of the three-phase project was the removal of the Lower Shannock Falls which included the installation of rock weirs and bank stabilization.

Agencies: Wood Pawcatuck Watershed Association (WPWA)-lead, NOAA, RIDEM, CRMC, USFWS, and many others project partners and funding sources.

Timeline/Progress: Completed, Fall 2010

Action 5) Horseshoe Falls Dam Denil Fishway

Description of Work: Construction of a new Denil fishway, juvenile bypass chute and self-regulating eel ramp.

Agencies: Wood Pawcatuck Watershed Association (WPWA)-lead, NOAA, RIDEM, CRMC, USFWS, and many others project partners and funding sources.

Timeline/Progress: Completed Fall 2012, RIDEM/Fish and Wildlife is currently operating and maintaining the Denil fishway and eel ramp.

6) Kenyon Mill Dam Rock Ramp Fishway

Description of Work: Removal of existing dam and installation of a new rock ramp fishway. The rock ramp fishway features a series of pools, constructed of natural stone weirs to facilitate fish passage.

Agencies: Wood Pawcatuck Watershed Association (WPWA)-lead, NOAA, RIDEM, CRMC, USFWS, Kenyon Mill Industries and many others project partners and funding sources.

Timeline/Progress: Completed March 2014.

Water Quality

Water Quality Restoration Program: RIDEM/Office of Water Resources administers the federal Clean Water Act program that undertakes studies and develops plans for restoring water quality known as "TMDLs". In collaboration with the State of Connecticut, RIDEM is undertaking a water quality study of the Pawcatuck River watershed to provide the technical basis for potential future actions to reduce nutrient pollutant to the downstream estuary. A previous TMDL for this watershed focused on bacterial pollution. http://www.dem.ri.gov/programs/water/quality/restoration-studies/ In the Pawtuxet River, implementation of a plan to upgrade wastewater treatment facilities to reduce nutrient pollutant loadings resulted in improved dissolved oxygen conditions in the Pawtuxet River that restored compliance with state water quality criteria (2008).

Water Quality Protection Programs: RIDEM/Office of Water Resources administers federal and state authorized programs which support a variety of actions to protect water quality and aquatic habitats. Programs include financial support for stormwater mitigation projects and other non-point pollution water quality protection actions including restoration of riparian buffers and stream connectivity as well as water quality monitoring and assessment, watershed planning and technical assistance activities.

Project Permit/Licensing Review Program: RIDEM/Office of Water Resources administers the federally delegated program for management of the point source discharge of pollutants (Rhode Island Pollutant Discharge Elimination System – RIPDES). This program encompasses sanitary, industrial and thermal discharges as well as stormwater runoff. http://www.dem.ri.gov/programs/water/permits/ripdes/ Additional RIDEM/OWR permitting programs also regulate and provide for the review of proposed water withdrawals and other hydromodifications, dredging projects, most land use development as well as other activities that would alter freshwater wetlands. http://www.dem.ri.gov/programs/water/permits/

Restoration Programs

RIDEM has partnered with the USFWS North Attleboro Fish Hatchery with the American shad fry stocking program. Each spring adults from the Connecticut River are delivered to the hatchery where they are allowed to naturally tank spawn. The fry are released throughout the summer into the upper reaches of the Pawcatuck River. The adult shad broodstock are allocated annually to RIDEM from the Connecticut River via CRASC approval

In the past, the state of Rhode Island has informally adopted a recovery target of 5,000 spawning adults, the restoration level recommended by Richard St. Pierre from the USFWS. Estimates for American shad carrying capacity per acre, were calculated from the models developed by St. Pierre, 1979; Hightower and Wong, 1997; and Weaver et al., 2003. These numbers are generally regarded as the benchmark for American shad restoration. The calculated target levels are greater than the past estimates of American shad observed at the Potter Hill fishway trap in any given year (1985-4,219 highest total).

Monitoring

Since 1979, American shad monitoring at the Potter Hill fishway trap in Ashaway, R.I is conducted using the standardized protocol described by O'Brien (1986). The trap located at the upstream end of the ladder is checked daily from late-March to July 1st. Data on the number of shad captured in the fishway trap, water temperature and water level are recorded daily. In addition, since 1986, weekly seining for juvenile shad and river herring is conducted in the lower Pawcatuck River from August to November. The five standard seine stations are sampled using the protocol established by O'Brien (1986). Juveniles of all anadromous species are enumerated, and lengths are measured. Presence and number of individuals of other species are also noted. Bottom water temperature, salinity and dissolved oxygen are measured.

Adult shad spawning stock size (SSS) and juvenile abundance indices (JAI's) are used as a guideline and metric to determine if the shad run on the Pawcatuck River is self-sustaining and restored. Target goals and baselines will be selected utilizing three year running averages and percentiles by RIDEM and partners following multiple years of increased SSS at the trap and seine survey JAI's. Since 2003, the SSS has been low.

Each year a sub-sample of adult shad are sampled at the fishway trap and growth, age, mortality, and percent of repeat spawner data is estimated to fulfil USFWS federal aid and ASMFC compliance requirements. American shad have been monitored since 1979 on the Pawcatuck River and numerous reports provide biological characteristic time series (Edwards, 1999, 2007. McGee, 2019).

Recommended Action(s)

- Explore passage improvements. Partners are currently working on improvement options at Potter Hill Dam and the Cronan gauge station.
- Continue Working with the USFWS and CRASC to stock American Shad fry into the Pawcatuck River.
- Collect genetic samples to identify origin of stock (hatchery reared).
- Continue monitoring via SSS counts and annual JAI surveys.

I. Habitat Assessment: Pawtuxet River

In 2011, the partial dam removal was completed at the Pawtuxet Falls Dam. The project included many partners including the Pawtuxet River Authority (PRA), NRCS, USFWS, NOAA, RIDEM, CRMC, Narragansett Bay Estuary Program (NBEP), Save the Bay, American Rivers, and many others. After an alternative analysis and review the partial dam removal option was considered the best alternative for American shad and river herring. Anadromous fish have access to over 7 miles of main stem river to the Pontiac Dam. The third obstruction is the Natick Pond dam. Feasibility for fish passage at both sites is at the preliminary stages. Since the dam being removed in 2011, RIFW has stocked adult broodstock river herring and has partnered with the USFWS North Attleboro Fish Hatchery to introduce American shad fry. Both stocking programs are planned to continue into the future.

Threats Assessment: Pawtuxet River

<u>Barriers to Migration</u>

Description:
In its *2002 Strategic Plan for the Restoration of Anadromous Fishes to Rhode Island's Coastal Streams* (Erkan 2002), the Rhode Island Department of Environmental Management (RIDEM) recognized the potential for significant expansion of river herring and American shad habitat by restoring fish passage to the mainstem Pawtuxet River. The plan identifies the first dam in Pawtuxet Village as an obstruction to migratory fish and with the removal opened over 7 miles of riverine habitat. Preliminary discussions have occurred for fish passage on the second obstruction, Pontiac Mills, which would open an additional 3 miles. Currently the 2002 plan is scheduled to be updated in 2020/2021. In addition, since 2001, RIDEM/Fish and Wildlife prepares an annual priority list of fish passage projects for river systems throughout the state. Since the inception, the Pawtuxet River fish passage projects have been a high priority (Edwards 2019).

Action 1) Partial dam removal at Pawtuxet Falls

Description of Work:
Partial dam removal at Pawtuxet Falls with a low channel slot to enhance migration during low water flows.

Agencies: NBEP, RIDEM, NRCS, NOAA, CRMC, PRA, Save the Bay, USFWS, American Rivers and many others.

Timeline/Progress: Completed during the Fall of 2011.

Water Quality

Water Quality Restoration Program: RIDEM/Office of Water Resources administers the federal Clean Water Act program that undertakes studies and develops plans for restoring water quality known as "TMDLs". In collaboration with the State of Connecticut, RIDEM has undertaken a water quality study of the Pawcatuck River watershed to provide the technical basis for potential future actions to reduce nutrient pollutant to the downstream estuary. A previous TMDL for this watershed focused on bacterial pollution. http://www.dem.ri.gov/programs/water/quality/restoration-studies/ In the Pawtuxet River, implementation of a plan to upgrade wastewater treatment facilities to reduce nutrient pollutant loadings resulted in improved dissolved oxygen conditions in the Pawtuxet River that restored compliance with state water quality criteria.

Water Quality Protection Programs: RIDEM/Office of Water Resources administers federal and state authorized programs which support a variety of actions to protect water quality and aquatic habitats. Programs include financial support for stormwater mitigation projects and other non-point pollution water quality protection actions including restoration of riparian buffers and stream connectivity as well as water quality monitoring and assessment, watershed planning and technical assistance activities.

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RIDEM has partnered with the USFWS North Attleboro Fish Hatchery with the American shad fry stocking program. Each spring adults from the Connecticut River are delivered to the hatchery where they are allowed to naturally tank spawn. The fry are released throughout the summer into the upper reaches of the Pawtuxet River. The adult shad broodstock are allocated annually to RIDEM from the Connecticut River via CRASC approval.

Monitoring

Compared to the Pawcatuck River, the lower Pawtuxet River is a challenging system to monitor anadromous fish due to site access, lack of traditional fishways, and absence of past time series.

During the construction of the partial dam removal a maintenance and emergency access ramp was built and left in place allowing RIDEM to monitor the presence and absence of juvenile anadromous fish utilizing boat electrofishing techniques. Electrofishing surveys for adults in the spring and juveniles in the fall were conducted with success, as juvenile shad were sampled in the fall showing fry survived the summer months following stocking. Currently the new RIFW electrofishing boat cannot be launched from the ramp due to its size, erosion issues at the launch, and previous materials used at the launch. Repairs with required permits are planned for the ramp and in the future RIFW will conduct spring and fall electrofishing surveys for both adults and juveniles. RIDEM recently purchased a Smith Root SR-7 tote barge equipped with a 2.5 GPP electrofishing system. This equipment will be used to complete a spring adult shad survey and a fall juvenile abundance survey in order to initiate a monitoring time series in the Pawtuxet River. In combination with RIDEM Smith Root electrofishing boat equipped with a 7.5 GPP electrofishing at river locations where wading is not possible. Using a combination of the two types of equipment, RIDEM Fish and Wildlife will be able to adequately survey the Pawtuxet River and collect data on shad returns and reproductive success.

Adult shad CPUE and juvenile JAI's will be used as a guideline to determine if the shad run on the Pawtuxet River is self-sustaining and restored. Target goals and baselines will be selected by RIDEM and partners following a few years of monitoring spawning stock size CPUE and juvenile abundance indices via electrofishing techniques.

Recommended Action(s)

- Explore options for future passage installations and improvements.
- Fish passage options at the Pontiac Dam are being reviewed by partners, while passage options at the Natick Dam, and Pocassett tributary are also being explored.
- Continue Working with the USFWS and CRASC to stock American Shad fry into the Pawtuxet River.
- Address access issues in order to resume electrofishing surveys, including adult monitoring and JAI's.

References

ASMFC. 2020. American Shad Benchmark Stock Assessment and Peer Review Report. Washington, D.C.

Edwards, P. A. 2020. Fish Passage Improvements. Rhode Island Division of Fish and Wildlife, Freshwater and Anadromous Fisheries Section. Annual performance reports to USFWS, Project F-26-R-48, Washington, D.C.

Edwards, P. A. 2017. Restoration and establishment of sea run fisheries. Rhode Island Division of Fish and Wildlife, Freshwater and Anadromous Fisheries Section. Annual performance reports to USFWS, Project F-26-R-52, Washington, D.C.

Edwards, P. A. 2014. American Shad Habitat Plan for the Pawcatuck River. Rhode Island Division of Fish and Wildlife, Freshwater and Anadromous Section. Report submitted to the Atlantic States Marine Fisheries Commission as a requirement of Amendment 3 to the Interstate Management Plan for Shad and River Herring.

Edwards, P.A., Lee, L.M., Hattala, K., and Kahnle, A. 2007. Status of the Pawcatuck River, Rhode Island American shad stock. Section 5 of the stock assessment report No. 07-01 of the Atlantic States Marine Fisheries Commission. Washington, D.C.

Edwards, P. A. 1999. State of Rhode Island American shad recovery plan 2000-2004. Rhode Island Division of Fish and Wildlife, Freshwater and Anadromous Fisheries Section. Report to the Atlantic States Marine Fisheries Commission. Washington, D.C.

Erkan, D.E. 2002. Strategic Plan for the Restoration of Anadromous Fishes to Rhode Island Coastal Streams. RI DEM, Division of Fish and Wildlife. Completion Report in Fulfillment of Federal Aid in Sportfish Restoration, F-55-R.

Hightower, J. E., and R. Wong. 1997. Potential benefits to anadromous fishes of providing fish passage within the Roanoke River basin. Report to the U.S. Fish and Wildlife Service and Virginia Power, Raleigh, North Carolina.

McGee, P. 2020. Restoration and establishment of sea run fisheries. Rhode Island Division of Fish and Wildlife, Freshwater and Anadromous Fisheries Section. Annual performance reports to USFWS, Project F-26-R-53, Washington, D.C.

O'Brien, J.F. 1986. Shad Restoration Studies. Performance Report. Project F-26-R-2. Rhode Island Division of Fish & Wildlife. 15 p. Appendix.

Hyle, Reid. 2017. American Shad Sustainable Fishing Plan Update for Florida, St. Johns River. Report to the Atlantic States Marine Fisheries Commission. Washington, D.C.

St. Pierre, R. A. 1979. Historical review of American shad and river herring fisheries of the Susquehanna River. U.S. Fish and Wildlife Service, Special Report to the Susquehanna River Basin Committee, Harrisburg, Pennsylvania.

Weaver, L. A., M. T. Fisher, B. T. Bosher, M. L. Claud, and L. J. Koth. 2003. Boshers Dam vertical slot fishway: a useful tool to evaluate American shad recovery efforts in the upper James River. Pages 339–347 *in* K. E. Limburg and J. R. Waldman, editors. Biodiversity, status, and conservation of the world's shads. American Fisheries Society, Symposium 35, Bethesda, Maryland.

Figure 1: Location of the Pawcatuck River Fish Passage Restoration Sites.

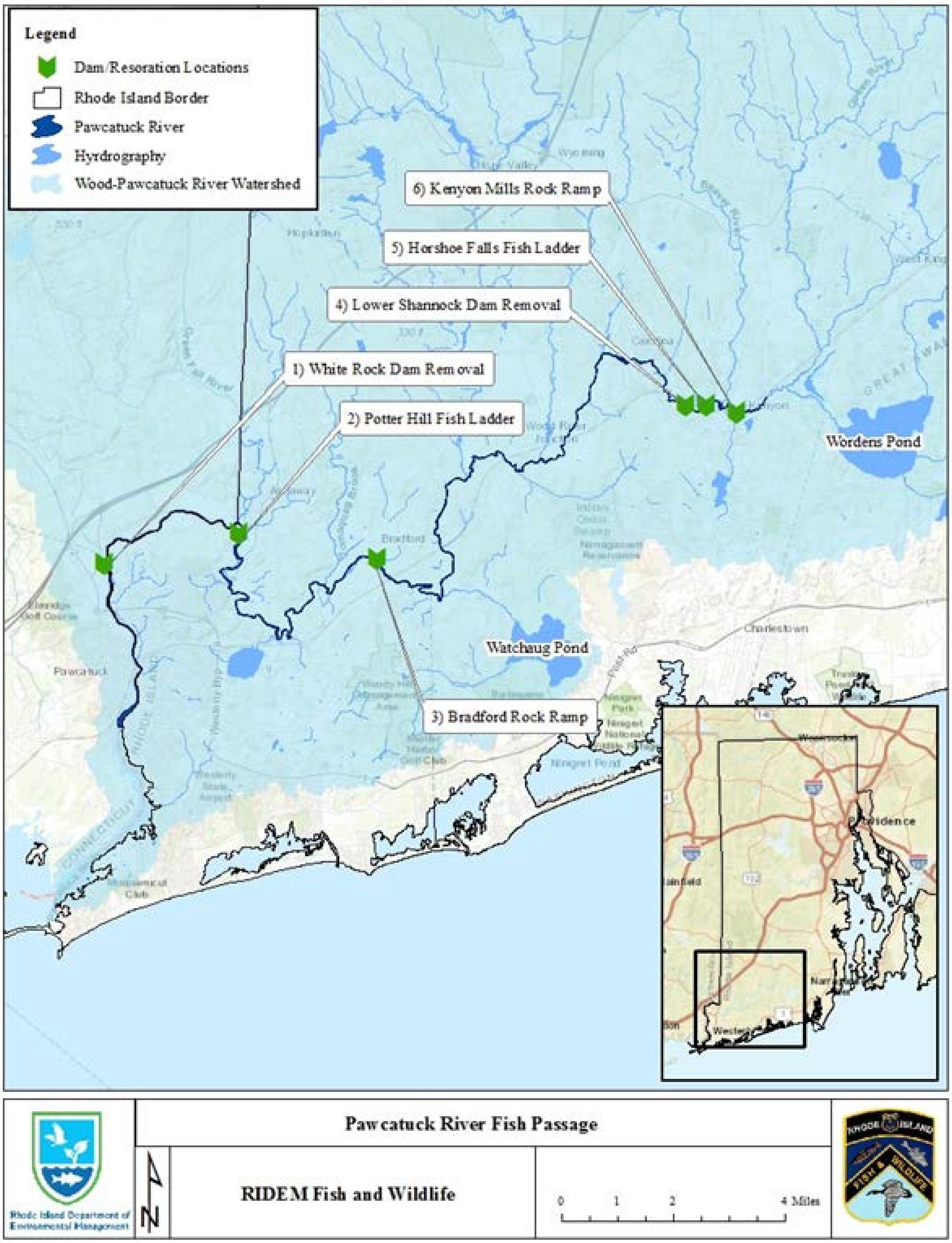
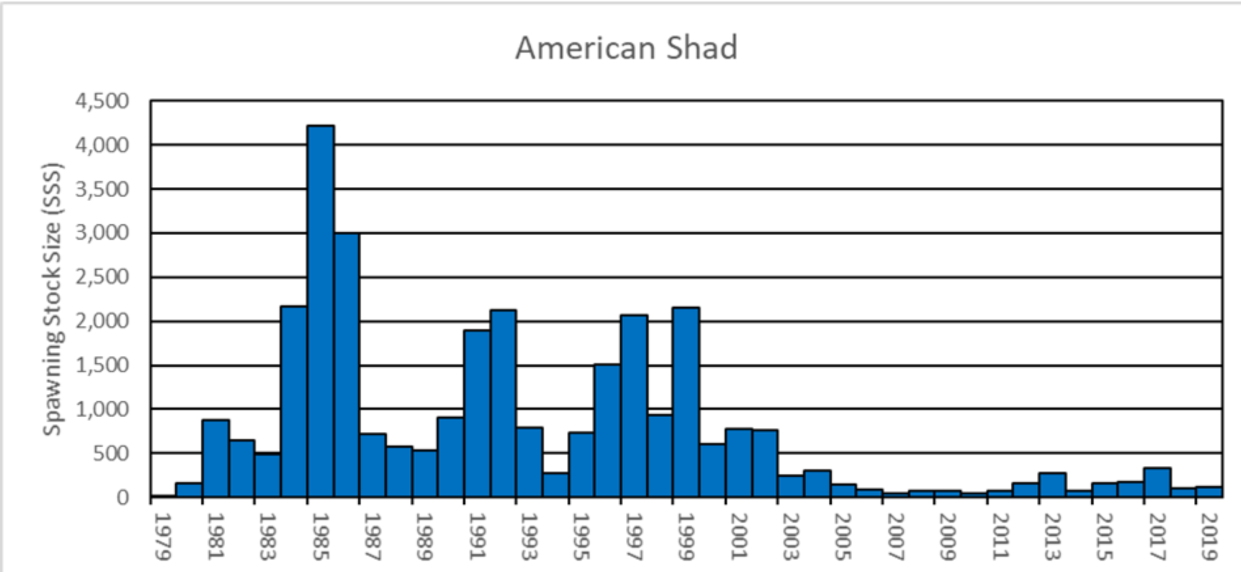


Figure 2: American shad spawning stock size from the Pawcatuck River.



Fishway Trap Counts
Pawcatuck River

Year	A. shad	Year	A. shad
1980	165	2000	608
1981	882	2001	774
1982	644	2002	768
1983	491	2003	243
1984	2,163	2004	301
1985	4,219	2005	151
1986	3,000	2006	92
1987	724	2007	44
1988	580	2008	70
1989	533	2009	69
1990	904	2010	44
1991	1,900	2011	78
1992	2,119	2012	156
1993	797	2013	279
1994	270	2014	72
1995	740	2015	159
1996	1,508	2016	169
1997	2,061	2017	331
1998	936	2018	103
1999	2,149	2019	115

Figure 3: Location of the Pawtuxet River Restoration Sites.

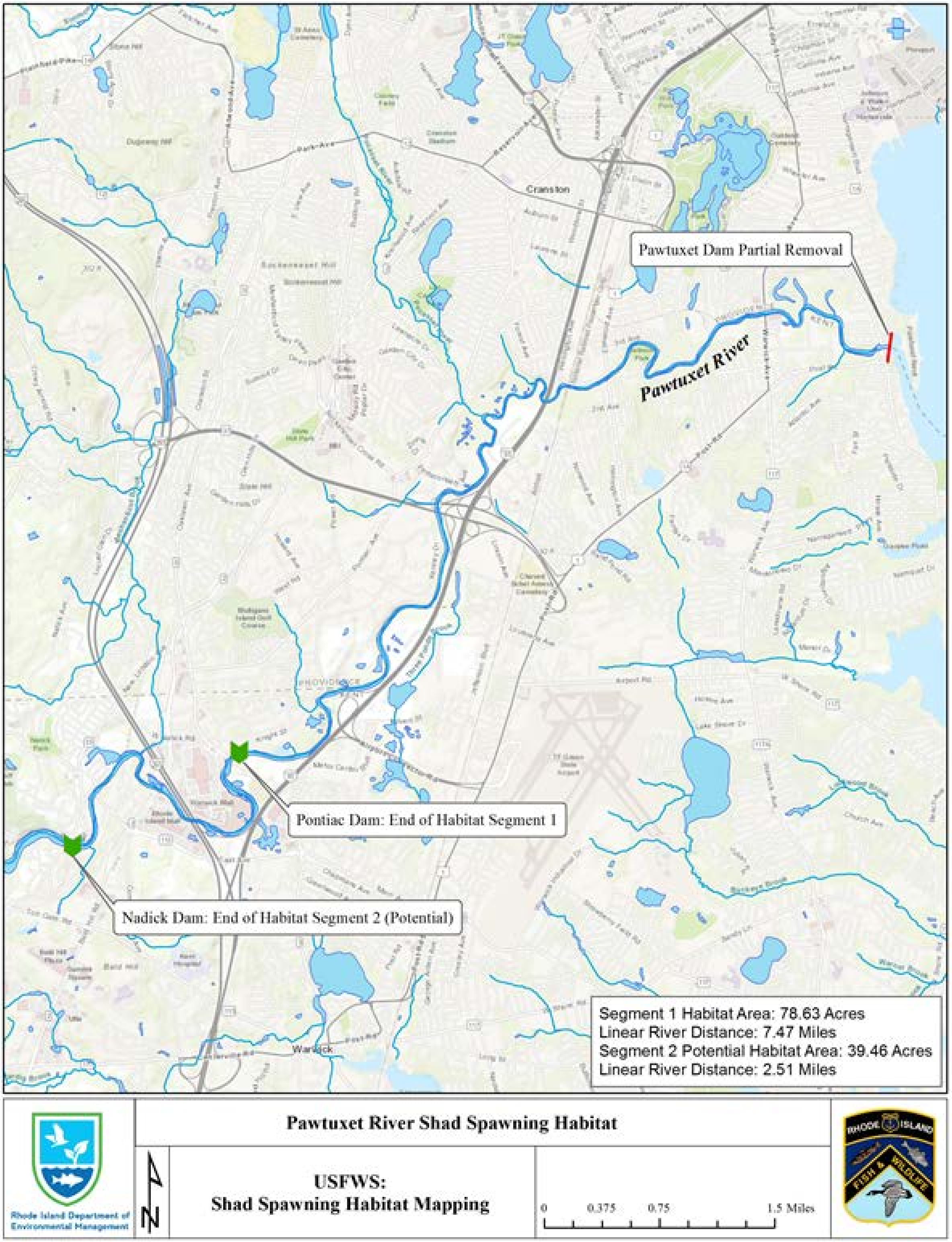


Table 1: Pawcatuck River segments and associated river miles.

Restoration Segments	**Segment ID**	**Distance (Miles)**
Route 1 (Westerly) to former White Rock Dam	1	2.26
Former White Rock Dam to Potter Hill Fish Ladder	2	3.34
Potter Hill Fish Ladder to Bradford Fish Ladder	3	7.12
Bradford Fish Ladder to former Lower Shannock Dam	4	12.02
Former Lower Shannock Dam to Horseshoe Falls Fish Ladder	5	0.48
Horseshoe Falls Fish Ladder to former Kenyon Mills Dam	6	0.87
Former Kenyon Mills Dam to Biscuit City Rd	7	0.73

Table 2: Pawcatuck River segments and associated river miles.

Habitat Segment	**Segment ID**	**Linear Distance (Miles)**	**Habitat (Acres)**
Mouth to Pontiac Dam	1	7.47	78.63
Pontiac Dam to Natick Dam (Potential)	2	2.51	39.46

State of Connecticut
American Shad Habitat Plan

Connecticut Department of Energy and Environmental Protection
Fisheries Division
Old Lyme, CT

April 2021

Introduction

The Atlantic States Marine Fisheries Commission (ASMFC) Amendment 3 to the Interstate Fishery Management Plan for American Shad requires all states to submit a Habitat Plan as part of their implementation plans, which also includes an approved Sustainable Fishing Management Plan (SFMP) for American Shad. The State of Connecticut submitted an initial Habitat plan that was approved in August of 2013. This document serves as an update to the 2013 plan. This update includes three sections: (1) Habitat Assessment, (2) Threats Assessment, and (3) Habitat Restoration Program. The Plan covers rivers and large streams in Connecticut that are known or suspected to have had American Shad runs. It is possible that some additional smaller rivers may have had American Shad, but historical documentation is lacking. There is no way to know if these small systems could historically have supported shad production or were benefactors of abundant adult shad from other nearby systems straying into these areas.

1) Habitat Assessment-Assess the habitat (historic and currently available) and impediments to full utilization of the habitat.

Spawning & Rearing Habitat

Connecticut has a variety of sources of information on aquatic habitat including: historical accounts, watershed management plans, maps, present-day fish survey data, and staff knowledge of the rivers and features (e.g. falls, dams, human infrastructure), that were reviewed to identify downstream and upstream endpoints to historic and present-day shad runs and spawning and nursery habitat. The length of these stream reaches were measured using GIS. Habitat categories were assigned broadly without any effort to identify and quantify small river stretches (e.g. 300 m plots). Moreover, there can be considerable overlap with shad spawning and rearing habitat but such overlap was not considered. All river stretches were categorized as either spawning or rearing habitat from an empirical standpoint. No physical studies were conducted to definitively characterize areas.

The determination of the geographic extent of historical shad runs in Connecticut rivers comes from knowledge of natural waterfalls that would have blocked runs, topographical features or abrupt changes in river gradient that would have impeded shad migrations . It is difficult to determine what kind of habitat (i.e. spawning, rearing, or neither) existed historically in some river stretches that are now inundated by the headponds of dams and have otherwise been dramatically altered over the last centuries of human occupation and alterations. It was speculated that most of these impounded river stretches are currently categorized as rearing habitat. These stretches are also categorized as historic rearing habitat, although this assumption may not be accurate. Since most of the remaining large dams are not likely to be removed, when shad runs are given access to these areas, these impounded reaches provide some rearing habitat to the species, albeit with much changed criteria. Quantifying historic status of those systems where future changes are not likely, are irrelevant and not considered further.

The results of the spawning and rearing habitat calculations are summarized in Table 2 for those systems worth consideration. Historically, American Shad had access to 589 km of riverine habitat in Connecticut. Currently, the species has access to 359 km. For spawning habitat, the historical habitat is estimated to have included 244 km, while currently there are 141 km. For rearing habitat, the historical habitat is estimated to have included 384 km, while currently there are 262 km.

2) Threats Assessment-Inventory and assess the critical threats to habitat quality, quantity, access, and utilization.

a. Barriers to migration inventory and assessment-

i. *Inventory of dams*

Dams and other structures are known to block shad migrations and limit the amount of accessible habitat. In almost all these cases, dam construction preceded any kind of meaningful quantification of fish abundance and no new dams have been constructed within the last 50 years.

The New England District of the US Army Corps of Engineers (USACE) operates flood risk management dams for the entire CT River watershed that are located on the tributaries. Quarterly update reports are published for each of the six New England states, including Connecticut. The CTDEEP Bureau of Water Protection and Land Reuse's Water Planning & Management Division, maintains a computerized inventory of dams in Connecticut. There are over 4,000 dams in Connecticut and all of the rivers that supported historic shad runs have had one or more dams built on them. In those cases where the lowermost dams are close to saltwater, shad populations unique to those systems were eradicated. It may not be possible to restore shad runs to all of these systems or prove conclusively that these systems historically had self-sustaining runs. Some observed shad “runs” in smaller streams may have been a result of increased straying when abundance was high in larger, neighboring systems. In recent years it has been the policy of the CTDEEP that for restoring anadromous fish runs, dam removal is the most effective means to restore systems to a natural state. Shad are notoriously difficult to pass up fishways (Gephard and McMenemy 2004) and when a dam is removed, the need for a fishway is avoided. Even with functional fishways in these systems, threats to shad remain. First, there are inevitable issues associated with fishways: locating, ascending, fatigue while ascending, obstructions caused by debris in the fishway, or flow rates above or below the prescribed range of flows for the fishway design (Haro & Castro-Santos 2012). With rivers with multiple dams, delays could be additive, resulting in hours to weeks of lost migratory time. Some fishways may cause significant injuries and result in mortality, thus reducing the true number of spawning fish. There are also significant threats to shad during the downstream migration. Spent adults may not have access to, be able to find, or use downstream passageways, resulting in injury or death and thus reducing the repeat spawning segment of the population. Fish not using downstream passage devices, or if there are none, have to utilize the spillway or turbine passage and may suffer injury or mortality. Repeat spawners are among the most valuable components of the spawning run as they are generally older, larger fish that produce both higher number and better quality of eggs.

The CTDEEP has worked with The Nature Conservancy and the Northeast Association of Fish and Wildlife Administrators on the Northeast Aquatic Connectivity Project (Martin and Apse 2011) to inventory and analyze Connecticut dams for their impact on connectivity to anadromous fish habitat. These databases are available, but are not included herein. They have been assessed to estimate their potential impact on shad runs. The results of that assessment lists dams that block shad runs and impact CTDEEP plans to restore shad runs (Table 3).

ii. *Inventory of other human-induced physical structures*

It is recognized that things other than dams can create migratory barriers to shad. No inventory of alternative barriers is provided because there are no known impassable culverts in Connecticut that block shad migrations. Culverts are a concern for fragmenting habitat for some anadromous and freshwater resident species. In general, these impassable culverts are more common in headwater streams and smaller rivers, well upstream of the range of American Shad, which tends to stay in larger rivers.

iii. *Inventory of altered water quality and quantity*

Historically, rivers and streams throughout New England were known to have greatly degraded water quality (Mullaney 2004). Hypoxia of water bodies was a concern during the era of heavy industrialization and pollution. Rivers or stretches of rivers containing degraded water quality may have served as temporary impediments or actually blocked shad migration. The Connecticut River, once famously referred to as America's "best landscaped sewer," has a long history of poor water quality due to heavy industrial expansion of textiles, heavy metal processing, logging and sewage (Mullaney 2004; Mullens and Bristow 2003). Water quality issues, discussed in subsequent sections, can include: low dissolved oxygen, low flow rates, and plumes of toxic or heated effluent. CT DEEP has developed regulations and has completed classifications for stream flow throughout the state.

The CT DEEP Long Island Sound Trawl Survey compared catches of marine species in the Narrows portion of Western Long Island Sound with levels of Dissolved oxygen (DO). American shad were not observed at sites where DO was below 2mg/L (Howell and Simpson 1994).

Connecticut has been progressive in the development of water quality management following some the dismal times of heavily polluted waters. An example is the development of Connecticut's Clean Water Act (1967), which was 5 years ahead of the Federal Clean Water Act of 1972.

The impetus for modern day American Shad studies by the CT DEEP is the continuation of efforts from a legislative demand to study the effects of heated water from a Nuclear Power Plant (Merriman and Thorpe 2004). The initial concern was that the plume of heated water, which could stretch across the river could impede and or block the annual shad spawning run. This was found not to be the case.

Modern day pollutants are also known to include a wide variety of subtances: road salts, microplastics, and pharmaceuticals. Pharmaceuticals may act as hormone and endocrine disruptors (Lara-Martín et al. 2014) that could impact and or preclude normal spawning or successful recruitment of future year classes. These potentially limiting factors, and other 'modern' concerns including nuisance aquatic species, and climate change and their potential impacts on shad stocks have not yet been adequately addressed, but need to be considered when considering the additional time, effort and money to be spent on shad restoration efforts.

iv. *Assess barriers to migration in the watershed*

Impingment/entrainment at dams- In addition to creating delays to the downstream migration, downstream migrants may be drawn into industrial intakes or impinged and killed. One issue is the turbine intake for hydroelectric projects which may have the strongest water flows at the dam. Turbines will kill the majority of adult shad that attempt to pass downstream through this system. Turbine mortality of young-of-year shad is more variable, but could potentially be significant in some systems. Other types of intakes include: pumped storage projects, irrigation, cooling water systems, and drinking water intakes. Most life stages, particularly smaller younger life stages like larval fish drawn into these intakes experience 100% mortality, and these impacts can be significant.

b. <u>Water withdrawals inventory and assessment</u>

In addition to potentially injuring or killing migrants by damaging the fish or drawing them into industrial filters and processes, water withdrawals can also impact migrations or access to spawning habitat, by reducing the available stream flow in the river. Withdrawals from a large river like the Connecticut are relatively minor when compared to overall river flow, and are thought to have minimal impacts in modern times. Withdrawals from small to medium sized rivers can be substantial and may drastically reduce the available water during the summer rearing period. Permitted water withdrawls from the Quinnipiac River combined with drought conditions dried up several streams during the summer of 1999 (Ahearn 2000). Water reduction in these smaller systems can also result in the rapid warming of the remaining river water.

The CT DEEP Water Diversion Program regulates activities that change water flow from any water bodies throughout the state. The Water Diversion Policy Act is codified in the both the CT General Statutes and within the Regulations of Connecticut State Agencies. Water diversions are identified and mapped by regions (East, Central, and West) in the state and can be found on the CT DEEP website.

c. <u>Toxic and thermal discharges</u>

While historically a substantial issue, since the passage of the clean water act, these types of discharges have not been permitted into CT waters. All discharges into Connecticut waters are carefully regulated by the CTDEEP. There may be episodic events, such as the 2019 accidental release of tens of thousands of gallons of PFAS chemicals into the Farmington River during a fire emergency at Bradley International Airport in June of 2019 (Hartford Courant 2019) or from other accidents, but these are not scheduled events and can not be prevented.

The Long Island Sound Study Comprehensive Conservation and Management Plan (LISS CCMP 2015) discusses the inventory of natural and man-made toxic substances in LIS. Overall, the quality of LIS waters is good with respect to toxic substances. Contributions of toxic substances in LIS can often originate from the major rivers. One of the documented substances of concern is PCBs, which is discussed in the atmospheric deposition section of the document. Sewage treatment plants are likely the second largest source of toxic substances.

Both the Connecticut and Quinebaug are examples of rivers that receive thermal discharges. Past research has determined that these discharges were not shown to have a negative impact on American shad. The CT DEEP Water Monitoring Group's Healthy Waters Initiative monitors water termperatures at wadeable river and streams throughout Connecticut. The state of Connecticut reviews municipal and industrial discharge permits to reduce the amounts of toxic pollutants to continue reductions of toxic materials in the waters. The USGS has gaging stations throughout CT that monitor streamflow and water quality parameters.

<u>d. Channelization and dredging</u>

The US Army Corps of Engineers of New England District oversees Connecticut Navigation projects. Channelization, stream straightening, burying sections of streams, and other projects that alter the morphology of streams are rarely proposed in Connecticut anymore and such activities are strictly regulated. The Fisheries Division has ample opportunity to comment on permit applications and would recommend denial of any permits that would adversely impact diadromous species, including American Shad.

The Port in New Haven Harbor (NHH) is the largest port in Connecticut and includes the mouth of the Quinnipiac River. Estimates of freight traffic in 2016 rank it as 24 percent of commerce by water in New England and 81 percent of commerce by water in Connecticut (USACOE 2021). The main channel is maintained at a depth of 35-40 deep to accommodate navigation.

Because of inefficiencies in large vessels transiting the harbor, USACOE is considering navigation improvements. The Environmental Impact Statements have been finalized for Essential fish habitat assessments for NHH.

e. Land use inventory and assessment

Connecticut has a long history of agricultural use that resulted in large amounts of deforestation through the 1850s (Yearsley et al. 2019). The soil of the Connecticut River floodplain was idea for agriculture. In the 20th century, much of the agricultural land has been converted to urban/sububrban land cover and forest. Information on Connecticut's geospatial data on on land use, including impervious surfaces, is available within CT DEEP GIS open data website.

The University of Connecticut (UCONN) Center for Land Use Education & Research (CLEAR) Connecticut's Changing Landscape Project (CCLP), analyzed changes to the state's landscape spanning 30 years of data from 1985-2015. During this timeframe, nearly 5 percent of state land was converted to development, with losses to forest and agricultural land. Analyses of land cover classifcications includes agricultural areas, riparian corridors, core forest and water shed imperviousness. There is public map viewer available that was designed to be useful for state and local governments (Arnold et al. 2020). In Connecticut, land use decision making occurs primarily at the municipal level. Connecticut has 169 municipal entities, each with its own land use plan and regulations.

Analysis of riparian areas analysis aids in the understanding and identification of streambank stabilization and sediment trapping. Since 1972, Connecticut implemented state legislation through the Inlands Wetlands and Watercourses Act. The law outlines the regulatory process to require municipal regulation and review of activities that affect inland riparian and wetland areas for environmental impacts

Connecticut is fortunate in that there still remains a high proportion of forested land in the state. Forest is the largest land cover class in Connecticut, followed by developed land, turf and grass and agricultural fields. The data analysis from the CCLP shows that, over the 30 years from 1985 to 2015, forest and farmland are being replaced by development. Analysis of impervious cover modelling for over 7,000 watersheds in CT shows an increase that is greater than 10%. Watersheds in western portions of the state have the highest percentages of impervious land cover. Much of the Quinnipiac, Housatonic and Thames Rivers have more than 25% of impervious land cover (Arnold et al. 2020).

While Connecticut has strong environmental laws, there are challenges with documenting and mitigating land use because regulations are decentralized. From 1985–2015, the state's population increased by about 12% (from 3.20 million to 3.59 million), while development increased by about 21%. Related to the health of the state's water resources are the estimates of watershed impervious cover that was generated from the CCLP land cover model. For the growth of the developed land category, the 30-year timespan shows that impervious cover at the small watershed scale continues to increase. This has resulted in 1,907 basin level watersheds reaching impervious levels of over 10%, a level widely considered to be harmful to water quality (Bellucci et al.2013). Reducing the amount and impact of impervious cover is a major focus of the state's newly enhanced General Stormwater Permit, a program of the federal Clean Water Act .

f. Atmospheric deposition assessment

There are documented impacts of atmospheric deposition, including the western portion of Conneccticut, where nitrogen pollution occurs from New York city to Long Island Sound. As a result, western LIS has been impacted by low dissolved oxygen levels, fish kills and algal blooms. Through efforts to protect LIS, human generated nitrogen pollution has been reduced over the last several decades. Mercury has also been documented as a large source of contamination to waters in Western CT along with sulfur and other trace metals (LISS 2015).

The Housatonic River has historically been and remains heavily contaminated with PCBs that orginated from the GE facility in Pittlfield MA. PCBs are present in large quantities in river sediment and floodplain soil with estimates range from between 100,000 to nearly 600,000 pounds (EPA 2020). The PCBs in sediment moves over dams and travels downstream into Connecticut. The PCBs are persistent in the environment and resistant to biodegradation. As a result, the rate of natural degradation of the type of PCBs in the Housatonic River is very slow. Without cleanup, it would take decades or possibly hundreds of years, before PCB concentrations would decrease. PCBs have been measured at very high concentrations in biota in the Housatonic River watershed, resulting in consumption advisories for fish in CT. The EPA negotiated a settlement agreement cleanup plan that includes Connecticut. Cleanup efforts have been underway and long term monitoring continues at several locations.

One of CT DEEP's management strategies to reduce nitrogen loading was to implement a trading program among the Water Pollution Control Facilities (WPCFs) throughout the state that are regulated under a general permit for Nitrogen discharge. When the state was out of compliance with TMDL allocations, 45 towns were required to purchase credits to remain in compliance. High water events and cold weather affect operations of WPCFs which contributes to increased levels of nitrogen being discharged. Revenue funds are expended towards nitrogen removal projects (CT DEEP 2018).

g. Climate change

Climate change impacts may have already resulted in faunal changes in distribution and abundance, but these changes have not yet been well quantified or analyzed in Connecticut rivers. The CT DEEP Long Island Sound Trawl Survey data was analyzed for changes in fish assemblage shifts as a result of changing water temperatures. Analyses of seasonal catches of cold-adapted marine species were negatively correlated with increasing bottom temperatures while warm-adapted species exhibited a positive correlation (Howell and Auster 2012).

Warming waters could modify the onset and duration of the American Shad spawning season, potentially greatly truncating it or causing a shift between the critical first feeding period and the availability of desired prey items. Shad stocks persist along a large latitudinal gradient, so it's unclear how warming trends will affect natal stocks on a coastwide basis. The rate of post-spawning mortality, and subsequently repeat spawning rate (iteroparity), is known to have a clinal trend. Dramatic declines in repeat spawning rates that have already been noted such that the annual spawning population are less robust and dependent upon fewer yearclasses in the run. This puts the stock at greater risk of spawning failure from one or more poor yearclasses. Additional climate change impacts could result in a further altered population structure, reduction in total annual egg deposition, and subsequent decline in run size or complete loss of the stock of American Shad in this system.

The River Sub-working group to Connecticut's Governor's Council on Climate Change (GC3) has identified important Climate challenges including: disruption to connectivity, shifts in geographic ranges of species, warming water temperatures, changes in flow regimes and precipitation patterns, increased frequency and intensity of heavy precipitation, runoff, and peak streamflow, increased frequency and intensity of droughts and flooding, disturbances to the geomorphic stability of rivers through the disruption of natural sediment processes, impacts to the migration of fish and wildlife species, sea level rise combined with increased frequency and intensity of storm surges and hurricanes.

h. <u>Competition and predation by invasive and managed species</u>

There are many non-native fish species in Connecticut, including non-native predators in the Connecticut River where there is a strong sustained shad run. While these species may cause some diminishment in numbers of shad, the impacts have not been quantified and the role of competition and predation in the context of human-induced impacts is unclear. Opportunities to study competition and predation by invasive and managed species or to extirpate non-native species is extremely limited. Past research using empirical monitoring and diet studies has determined that native species (e.g. striped bass) can have substantial predation impacts on adult alosine stocks (Davis et al. 2012; Savoy and Crecco 2004). Therefore, it would be reasonable to assume that there are additional predation impacts on shad stocks in Connecticut, particularly at the juvenile stage.

3) Habitat Restoration Program

For threats deemed to be of critical importance to the restoration of American Shad, each state should develop a program of actions to improve, enhance, and /or restore habitat quality and quantity, habitat access, habitat utilization and migration pathways.

The geographic scope of Connecticut's American Shad restoration efforts is summarized in Table 4, which lists the rivers, the targeted habitat and quantifies projected spawning and nursery habitat by river. This updated plan also reports on the progress made toward the CTDEEP's goals for habitat connectivity since the plan was first written in 2013.

Currently, shad have access to 383.8 km of habitat (2013= 360 km). The CTDEEP plan for restoration seeks to reconnect habitat and increase that to 610 km of habitat. The amount of historic habitat is estimated to have been 641.8 km.

The CTDEEP is pursuing the restoration of shad runs in a number of Connecticut streams. The Connecticut River is the best known shad river in the state and hosts one of the largest and most stable American Shad runs on the East Coast. It supports both recreational and commercial fisheries for shad. CTDEEP has an approved Sustainability Fishing Management Plan for this population. There are no barrier dams on the mainstem of the Connecticut River in Connecticut, the water quality is generally good, and the current levels of harvest are sustainable. Efforts to increase the size of the river population and the distribution of adult pre-spawners throughout the basin have been ongoing since 1976 when the first effective fish passage at the Holyoke Dam took place (Henry 1976). Since then, numerous structural and operational changes at Holyoke now result in 60% of the annual population being passed above Holyoke. CTDEEP participates with the other Connecticut River Basin States through the Connecticut River Atlantic Salmon Commission (CRASC). CRASC is a multi-state/federal partnership established by an act of the US Congress to specifically manage Atlantic Salmon (https://www.cga.ct.gov/Current/pub/chap_494.htm), but has expanded management efforts to other diadromous species throughout the basin. The American Shad population in the Connecticut River has not reached the restoration goals established by CRASC, despite more than 40 years of significant effort, suggesting that there are additional impacts in the Basin to consider.

The CTDEEP had been working to restore shad runs to three Connecticut River tributaries within Connecticut: the Farmington, Mattabesset, and Scantic rivers, by fishway construction, dam removals and trucking prespawn adults. It has been noted in this document and in ASMFC documents, that shad are a large river, mainstem species. Ecologically, this is one way to ensure adequate separation among the three con-specifics that co-occur in many East Coast systems, American Shad predominately spawning in the mainstem and river herring (collectively) spawning in tributaries. It has never been conclusively documented that there are genetically distinct populations of American shad within Connecticut River tributaries; it is possible that all American shad spawning in the Connecticut River are from a single genetic population, and the abundance of spawners in any one tributary in a given year is simply a product of variation in adult shad behavior and prevailing environmental conditions.

Adult shad abundance in those systems where numbers are collected show some correlation with mainstem abundance, i.e. a simple percentage. If annual run size to these systems was correlated to juvenile production in those sytems in previous years (i.e. strong natal site fidelity), we would expect to see systematic increases in abundance as new areas colonized typically have good production until reaching carrying capacity. Fishway counts do not indicate this in the Farmington River system where we have data since 1976. The failure of this system to produce increases in this population could be a result of ineffective shad passage (upstream and downstream) at the first dam (Rainbow Dam) known from direct observation and or other factors including the Farmington River not being optimal American Shad habitat. Estimates of the numbers of shad from the Scantic system don't exist and counts of shad began recently (2013) on the Mattabesset River system.

In addition to the Connecticut River, the CTDEEP seeks to restore and enhance runs of American Shad in a number of other rivers that flow into Long Island Sound. It should be noted that some of these systems may have lost whatever stocks were natal to these systems and that any remenant run size is believed to be reduced from the historic abundance.Whether adult shad transplanted from a large river system (Connecticut River) will establish annual runs in these smaller systems remains unknown. Each of these rivers is reported in this document. The CTDEEP has not submitted a SFMP for any of these other rivers and has prohibited harvest of shad in each of these other rivers until the populations have grown to the level where a SFMP could be considered. In all cases, the impediment to full utilization of historic habitat is the presence of barrier dams.

Water quality improvement

The CT DEEP GIS open data website contains data layers that include estuaries that have been assessed in compliance with sections 305(b) and 2020(d) of the federal Clean Water Act. 305 (b), which requires each state to monitor assess and report on the quality of water relative to attainment of designated uses establisted by the state's water quality standards. States are required to compile a list identifying waters not meeting water quality standards and assign a Total Maximum Daily Load (TMDL) priority ranking to each impaired waterbody.

Connecticut's permit programs and monitoring for direct and indirect sources of water quality impairment, have resulted in large reductions in water pollution over the past several decades. These improvements to water quality in Connecticut streams have progressed to the point where it is unlikely to be a major impediment to restoring American Shad runs. Some streams could benefit from further improvement of water quality and improvements could increase survival of young-of-year shad. However, our assessment concludes that such reduced water quality is not a significant obstacle to shad in recolonizing historic habitat.

Barrier removal and fish passage program

Connecticut is a heavily dammed state with over 3,000 dams within its borders—the exact number is unknown (Kennedy et al. 2018). These dams were a major factor of the demise of all diadromous fish runs in the state and remain a significant challenge in restoring these runs. Some runs of American Shad have been totally eliminated or reduced to very few fish. Migratory barriers remain a significant threat to American Shad populations in some systems in Connecticut.

The CTDEEP fish passage program has historically sought to either remove a dam, or failing removal, build a fishway around the dam. The removal of a dam precludes the need for a fishway and reduces problems with downstream passage. In theory, this restores native habitat (perhaps historic spawning habitat long since inundated) and reduces impoundments that often favor non-native predators. However, many dams cannot be removed for a variety of reasons, most notably because they are still valued (e.g. hydroelectric projects). For these dams, the CTDEEP seeks the provision of fishways, either through a voluntary process or through regulatory processes. The CTDEEP is acutely engaged in all licensing and re-licensing procedures for hydroelectric projects in Connecticut by the Federal Energy Regulatory Commission (FERC). The CTDEEP works very closely with the U.S. Fish & Wildlife Service (USFWS) in these procedures. In addition, the State of Connecticut has statutes that authorize the CTDEEP to require a fishway at dams not regulated by FERC. However, most fish passage projects in Connecticut are not pursued through any regulatory process but instead follow a voluntary process. The CTDEEP works with many municipalities and non-governmental organizations (NGOs) like watershed groups, land trusts, fishing clubs, and larger conservation organizations in a coordinated regional approach in which the NGO sponsors the project, crafts all the necessary agreements, applies for grants to pay for design and construction, and oversees the construction while the CTDEEP provides continuous technical oversight. In a typical year, two or three fish passage projects are implemented in Connecticut and some of them benefit American shad.

Impingment/entrainment at dams-

This problem is addressed at regulated hydroelectric projects through the FERC licensing process. It is important to note that not all hydroelectric projects located in rivers targeted for shad restoration are regulated (licensed) by FERC and therefore fall outside this process. The most common source of this threat comes from hydroelectric projects and lack of suitable downstream passage. The CTDEEP works with the USFWS and FERC, and licensees during the licensing process to ensure the best state-of-the-art downstream fishway facilities are installed, maintained and operated at hydroelectric dams. Intakes for other industrial uses are assessed during the permitting process and the CT DEEP dictates the design and operation of these intakes to minimize impact on American Shad.

Water withdrawals

All water withdrawals from Connecticut streams of significant size must be permitted by the CTDEEP. The Connecticut Water Planning Council has published a comprehensive Water Plan (2017) for the state that includes a broad range of estimated Desired Ecological Flow levels basin-wide.

Project permit/licensing review program

The Fisheries Division Habitat Conservation and Enhancement (HCE) Program, routinely comments on permit applications and evaluates such applications on their potential impact on diadromous fish runs, including American Shad. Connecticut has more recent streamflow regulations that have tightened the regulation of water withdrawals and releases. CT DEEP Permit reviews include examination of CT DEEP GIS Open Data Website and the CT Natural Diversity Database

In the Quinnipiac River, existing water withdrawals have begun to impact the minimum flow levels during the summer rearing period. The CTDEEP has taken steps to eliminate some withdrawals and limit future withdrawals to protect fish habitat.

Programs to avoid, minimize, or mitigate associated impacts to American shad migration and utilization of historic habitat from climate change

Part of the mission of the CTDEEP is to guide the state into a more environmentally-responsive approach to generating and using energy. However, a potential impact of climate change to American Shad runs could include increasing water temperatures reducing the rate of repeat spawning, which would impact the stock's population structure and resiliency. Although this impact cannot be entirely avoided if the streams in the state experience temperature increases, the proposed monitoring within GC3 plans, will identify and potentially mitigate this impact to some extent

Climate change is a larger challenge that Connecticut will address at the State level, through the Governor's Council on Climate Change (GC3). In 2019, Connecticut's Governor Ned Lamont issued an Executive Order reestablishing and expanding the membership and responsibilities of the GC3. A primary objective to the GC3 includes developing and implementation adaptation strategies to assess and prepare for impacts of climate change including areas of natural resources. Proposed topics that could improve fish habitat include: exploring water rights options that protect fish and wildlife, support fish, wildlife, and ecological needs when balancing economic and social needs in decision-making processes, evaluate approaches to research, monitor, and address coastal acidification impacts to natural resources. More specific priority actions for rivers include advancing connectivity among habitats and addressing climate challenges.

Adult Shad Transplantation program

Some runs have been extirpated or reduced, but fish passage projects have recently or will soon reconnect critical shad habitat to Long Island Sound. This represents an opportunity to re-create a shad run where one may have existed in the past. Once 'opened', a run of shad in a system may expand if the run has not been extirpated or if strays from the Connecticut River or other systems recolonize the system. Whether these fish will successfully restore the run of shad to the river and how long this process could take remains unknown. To accelerate the pace of restoration, some systems are 're-seeded' by stocking pre-spawn adult shad

Due to the strong run size of shad to the Connecticut River and the presence of modern trapping facilities at the first dam at Holyoke, MA, the CTDEEP implemented an active transplantation program in which pre-spawned adults from the Connecticut River were collected at the Holyoke Dam Fishlift, placed in a specially-designed transport tank truck, and driven to the restoration rivers, where they are released. Success of relocation of pre-spawn shad may vary for a number of reasons, including fish dropping downstream prior to spawning, delayed mortality due to handling and transport stess. Additionally, the collection method includes taking an opportunistic sample, with an unknown sex ratio, after the fish come out of the elevator lift cycle. The fish are diverted to a holding tank, where they are transferred to the truck tank. The shad are then released into new habitat that may not have been thoroughly evaluated for successful spawning and juvenile rearing habitat. There are also inherent risks asscociated with moving fish and water between watersheds including pathogens and species not native species. to the watershed targeted for shad restoration.

In recent years, shad moved throughout the Shetucket River were taken from the first dam on the Shetucket River (Greeneville Dam) so that currently shad transplanted throughout the Shetucket-Quinebaug river basin originate from the Shetucket River. Prior to this (1998-2010) Holyoke origin pre-spawn shad were trucked to the basin. The amount of fish transplanted into each river varies from year-to-year but typically ranges between 80 and 200 adult shad per river. The CTDEEP had conductedthese transplantation activities except for some transplantation in the Shetucket River that is conducted by the City of Norwich, Department of Public Utilities, which operates two hydroelectric projects with fishways. They had transplanted some shad using their own truck under the guidance of the CTDEEP. A list of rivers with recent transplantation programs is shown in Table 5.

Habitat Improvement program- The Fisheries Division HCE Program seeks to protect and restore fish habitat statewide. This work includes staff assigned to review permit applications for marine activities, such as dredging, dock construction, etc. This program staff works closely with the Diadromous Fish Program and routinely reviews permit applications with consideration of the impacts to diadromous species, including American Shad. Not only are conditions placed in permits to avoid or reduce any impacts to American Shad habitat and runs but sometimes habitat can be improved beyond its current condition due to mitigation agreements. Staff also proactively works with municipalities and NGOs on restoration projects to improve habitat for diadromous species. One example is the Moosup River Project in which six migratory barriers will be addressed in this system shad river. This project is funded through a mitigation fund provided by an upstream power plant and is supported by a partnership between the CTDEEP, three federal agencies, a municipality and an NGOs.

References

Ahearn, E. 2000. Streamflow in the Quinnipiac River Basin, Connecticut: Statistics and Trends.

Arnold, C., Wilson, E., Hurd, J., & Civco, D. 2020. 30 Years of Land Cover Change in Connecticut, USA: A Case Study of Long-Term Research, Dissemination of Results, and Their Use in Land Use Planning and Natural Resource Conservation. Land, 9(8), 255.

Bellucci, C. J., Becker, M. E., Beauchene, M., & Dunbar, L. 2013. Classifying the health of connecticut streams using benthic macroinvertebrates with implications for water management. Environmental Management, 51(6), 1274–1283.

Connecticut General Assembly Chapter 494 Connecticut River Atlantic Salmon Compact Sec 26-302 Compact for state membership in the Connecticut River Atlantic Salmon Commission.

Connecticut Water Planning Council 2018. Connecticut State Water Plan Final Report. 616p https://portal.ct.gov/Water/Water-Planning-Council/State-Water-Plan

CT DEEP. 2019. Long Island Sound Blue Plan Version 1.2. 514pp. blueplanfinaldraftversion12september2019pdf.pdf (ct.gov)

CT DEEP 2018. Report of the Nitrogen Credit Advisory Board to the Joint Standard Environment Committee of the General Assembly. 42pp.

CT DEEP GIS Open Data Website. CT DEEP GIS Open Data Website (arcgis.com)

CT DEEP Dam Safety Regulatory Program 2016. Dam safety regulations.

CT DEEP Inland Wetlands and Watercourses. Inland Wetlands and Watercourses home page (ct.gov)

CT DEEP 2020. Integrated Water Quality Report https://portal.ct.gov/DEEP/Water/Water-Quality/Water-Quality-305b-Report-to-Congress

Davis, J. P., Schultz, E. T., & Vokoun, J. C. 2012. Striped bass consumption of blueback herring during vernal riverine migrations: Does relaxing harvest restrictions on a predator help conserve a prey species of concern? Marine and Coastal Fisheries, 4(1), 239–251.

Gephard, S., & McMenemy, J. R. 2004. An Overview of the Program to Restore Atlantic Salmon and other Diadromous Fishes to the Connecticut River with Notes on the Current Status of these Species in the River. American Fisheries Society Monograph, 9, 287–317.

Haro, A., & Castro-Santos, T. 2012. Passage of American shad: Paradigms and realities. Marine and Coastal Fisheries, 4(1), 252–261.

Henry, S. 1976. Development of Fish Passage Facilities for American Shad at Holyoke Dam on the Connecticut River. Proceedings of a Workshop on American Shad.

Howell, P., & Auster, P. J. 2012. Phase Shift in an Estuarine Finfish Community Associated with Warming Temperatures. Marine and Coastal Fisheries, 4(1), 481–495.

Howell, P., & Simpson, D. 1994. Abundance of marine resources in relation to dissolved oxygen in Long Island Sound. Estuaries, 17(2), 394–402.

Kennedy, K., K. Lutz, C. Hatfield, L. Martin, T. Barker, R. Palmer, L. Detwiler, J. Anleitner, J. Hickey. 2018. The Connecticut River Flow Restoration Study: A watershed-scale assessment of the potential for flow restoration through dam re-operation. The Nature Conservancy, U.S. Army Corps of Engineers, and University of Massachusetts Amherst. Northampton, MA. Available: http://nature.org/ctriverwatershed

Lara-Martín, P. A., González-Mazo, E., Petrovic, M., Barceló, D., & Brownawell, B. J. 2014. Occurrence, distribution and partitioning of nonionic surfactants and pharmaceuticals in the urbanized Long Island Sound Estuary (NY). Marine Pollution Bulletin, 85(2), 710–719.

Long Island Sound Study 2015. Long Island sound Comprehensive Conservation and Management Plan. https://longislandsoundstudy.net/2015/09/2015-comprehensive-conservation-and-management-plan/

Martin, E. H. and C. D. Apse. 2011. Northeast Aquatic Connectivity: An Assessment of Dams on Northeastern Rivers. The Nature Conservancy, Eastern Freshwater Program.

Mullaney, J.R. 2004. Summary of Water Quality Trends in the Connecticut River, 1968-1998. American Fisheries Society Monograph 9: 273-286.

Mullens, J. B., & Bristow, R. S. 2003. Overcoming the nation’s best landscaped sewer: Recreators’ perceptions of the Connecticut River. In Journal of the American Water Resources Association (Vol. 39, Issue 1, pp. 7–15).

Naval Facilities Engineering Command Mid-Atlantic. 2017. Letter of Authorization Under the Marine Mammal Protection Act for the Demolition/Replacement of Pier 32/Demolition of Pier 10 at Naval Submarine Base New London Groton, Connecticut. Prepared for Naval Submarine Base New London. 97pp.

Savoy, T.F. and V.A. Crecco. 2004. Factors affecting the recent decline of blueback herring and American shad in the Connecticut River. American Fisheries Society Monograph 9: 361-377.

US Army Corps of Engineers, New England District. 2021. Update Report for Connecticut.

US Army Corps of Engineers, New England District. 2020. New Haven Harbor, New Haven, Connecticut Navigation Improvement Project Final Integrated Feasibility Report and Envrionmental Impact Statement.

US Army Corps of Engineers, New England District. 2021. Update Report for Connecticut.

Vaudrey, J. 2017. New York City's Impact on Long Island Sound Water Quality Techical Report. 33pp.

Yearsley, J. R., Sun, N., Baptiste, M., & Nijssen, B. 2019. Assessing the impacts of hydrologic and land use alterations on water temperature in the Farmington River basin in Connecticut. Hydrology and Earth System Sciences.

Table 1. List of rivers in Connecticut thought to have supported historical runs of American Shad.

Map #	Name*	Present-day Connecticut town(s) at mouth of river
1	Housatonic River	Stratford & Milford
2	Naugatuck River	Derby
3	Pomperaug River	Southbury
4	Shepaug River	Southbury and Bridgewater
5	Quinnipiac River	New Haven
6	Connecticut River	Old Saybrook & Old Lyme
7	Mattabesset River	Middletown & Cromwell
8	Farmington River	Windsor
9	Pequabuck River	Farmington
10	Scantic River	East Windsor
11	Shetucket River	Norwich
12	Quinebaug River	Norwich
13	Willimantic River	Windham

*left justified rivers are mainstem; indented streams are tributaries

Table 2. Assessment of historic and current habitat for American Shad in Connecticut. **Boldface** text identify rivers in which progress toward the goals have been achieved since the 2013 plan.

	Historic			Current			Habitat distance (Length in Kilometers): spawning		rearing- estuarine**		rearing- in-river	
River*	upstream end point	Town	Total km	Upstream end point	Town	Total km	historic^	current	historic	current	historic^	current
Housatonic	Great Falls	New Milford	46.9	Derby Dam	Shelton	21.1	21.7	1.4	19.4	19.4	21.6	0.9
Naugatuck	junction of E & W branches	Torrington	63.7	Tingue Dam	Seymour	9.7	24.3	3.5	0	0	19.6	6.2
Pomperaug	Gradient change	Woodbury	5.2	no run to mouth	n.a.	0	9.2	0	0	0	17	0
Shepaug	Roxbury Falls	Roxbury	6.4	no run to mouth	n.a.	0	1	0	0	0	5.4	0
Quinnipiac	**Interstate 84**	**Southington**	**47.8**	**Nickson Dam**	**Plainville**	**43**	**14.2**	**14**	**10.9**	**10.9**	**22.7**	**22.7**
Connecticut	MA state line	Enfield	108	MA state line	Enfield	108	32.3	32.3	24.3	24.3	51.4	51.4
Mattabesset	CT Route 71	Berlin	36.3	Kensington Dam	Berlin	36.3	15.65	15.65	0	0	20.65	20.65
Farmington	Satans Kingdom	New Hartford	80.8	Lower Collinsville Dam	Avon	60.3	46.4	29.8	0	0	33.4	29
Pequabuck	Middle Street	Bristol	15.9	Middle Street Dam	Bristol	15.94	4.9	4.9	0	0	11	11
Scantic	**Durkee Road**	**Somers**	**34.8**	**Somersville Dam**	**Somers**	**21.1**	**10.25**	**12.8**	**0**	**0**	**21.95**	**11.2**
Shetucket	**Willi-Natchaug conf.**	**Windham**	**28**	**Willi-Natchaug conf.**	**Windham**	**28**	**12.9**	**12.9**	**24.1**	**24.1**	**15.6**	**15.6**
Willimantic	source	Staffford Springs	37.7	AmerThread#1 dam	Windham	1.2	20.8	1.2	0	0	18.1	0
Natchaug	falls at Mansfield Hollow	Mansfield	5.8	Willimantic Res dam	Windham	2.5	2.5	2.3	0	0	3.3	3.3
Quinebaug	Cargill Falls	Putnam	57.5	Aspinook Dam	Griswold	11.9	21.2	9.8	0	9	36.3	2.1
Moosup	confluence w/Quanduck Bk	Sterling	14.5	no run to mouth	n.a.	0	7	0	0	0	7.5	0
Totals			589.3			359.0	244.3	140.6	78.7	87.7	305.5	174.1

*left justified rivers are mainstem; indented rivers are tributaries

**estuarine habitat is only listed for the river in which it is located even though runs in upstream tributaries (e.g. the Naugatuck) may benefit from such habitat.

Estuarine habitat within the Thames River (all estuary) is included under the Shetucket River, its main freshwater tributary.

^ "historic" habitat refers to existing habitat within the historic range. For example, historically a river stretch may have included free-flowing habitat suitable for spawning. When the habitat is inundated by a dam, the habitat is classified as rearing. When shad are reconnected to historic habitat in the future, it would be considered rearing habitat. Regardless, it is difficult to categorize historic habitat type in impounded systems.

Table 3. An inventory of key dams that block existing or planned runs of American Shad in Connecticut. Boldface text indicates change from 2013 Plan.

River	dam*	purpose	current fish passage	plans for future fish passage	comments
Housatonic	Derby	hydroelectric	none	fishway	currently under design
	Stevenson	hydroelectric	none	fishlift	FERC required timetable
	Shepaug	Hydroelectric	None	Fishlift	FERC required timetable
Naugatuck	Kinneytown	hydroelectric	Denil	monitoring	currently passes shad
	Tingue	**none**	**Bypass channel**	**repairs**	**Work about to begin**
	Plume-Atwood	none	none	removal	No plans at this time
Quinnipiac	Wallace	industrial water	Denil	monitoring	currently passes shad
	Hanover Pond	**town park**	**Denil**	**monitoring**	**currently passes shad**
	Carpenters	**none**	**full**	**none**	**Removed in 2016**
	Clark Brothers	**none**	**full**	**none**	**Removed in 2016**
Connecticut	Enfield	none	full	none	No longer exists
Mattabesset	StanChem	fire protection	Denil	monitoring	passes shad
Farmington	**Rainbow**	**hydroelectric**	**vertical slot**	**fish lift**	Poor shad passage/Trap and Truck Facility designed
	Spoonville	none	full	none	dam removed in 2012
	Winchell-Smith	none	partial barrier	removal	project on hold
	Lower Collinsville	none	none	removal	Currently under design
	Upper Collinsville	future hydro	none	Denil	Currently under construction
Scantic	**Springborn**	**none**	**full**	**none**	**Removed in 2018**

Table 3 Continued. An inventory of key dams that block existing or planned runs of American Shad in Connecticut. Boldface text indicates change from 2013 Plan.

River	**dam***	**purpose**	**current fish passage**	**plans for future fish passage**	**comments**
Shetucket	Greeneville	hydroelectric	fishlift	monitoring	currently passes shad
	Taftville	hydroelectric	Denil	continued monitoring	currently passes shad
	Occum	hydroelectric	Denil	continued monitoring	currently passes shad
	Scotland	**hydroelectric**	**none**	**fish lift**	**Constructed in 2018**
Willimantic	4 willimantic dams	hydroelectric	none	none	will consider restoring if other parties remove dams
Natchaug	Willimantic Water Works	water supply	none	none	restoration plans end at base of dam
Quinebaug	Tunnel	hydroelectric	Fishlift	continued monitoring	currently passes shad
	Aspinook	hydroelectric	None	fishlift	currently relicensing
	Rajak	hydroelectric	None	uncertain	future relicensing
	Rogers	uncertain	None	uncertain	will investigate after Rajak
Moosup	**Lower Kaman**	**none**	**Full**	**none**	**Removed in 2014**
	Upper Kaman	none	None	removal	Project planned
	Griswold Rubber	**comic relief**	**Full**	**none**	**Removed in 2016**
	Brunswick #1	**none**	**Full**	**none**	**Removed in 2017**
	Brunswick #2	none	None	Denil	future hydro development

Table 4. Summary of plans to restore and enhance runs of American shad in Connecticut with quantification of habitat types. **Boldface font indicates change from 2013 plan**. Underlined font indicates planned habitat connectivity work is completed. *left justified streams flow into Long Island Sound; indented streams are tributaries of the left justified stream listed above. Habitat distance (Length in Kilometers).

Existing				Targeted for Restoration			spawning		rearing- in-river	
River*	Upstream end point	Town	Total km	upstream end point	Town	Total km	current	targeted	current	targeted
Housatonic	Derby Dam	Shelton	21.1	Bulls Bridge Dam	New Milford	68.5	1.4	33.4	0.9	25.1
Naugatuck	Tingue Dam	Seymour	9.7	Thomaston F.C.D.	Thomaston	49.1	3.5	24.3	6.2	19.6
Pomperaug	no run to mouth	n.a.	0	mouth of Nonewaug	Woodbury	26.3	0	9.2	0	17
Shepaug	no run to mouth	n.a.	0	Roxbury Falls	Roxbury	6.4	0	5.4	0	6.15
Quinnipiac	**Nickson Dam**	**Plainville**	**47**	**Nickson Dam**	**Plainville**	**47.8**	**14**	**14**	**22**	**22**
Connecticut	state line	Enfield	108	state line	Enfield	108	32.3	32.3	51.4	51.4
Mattabesset	Kensington Dam	Berlin	36.3	Kensington Dam	Berlin	36.3	15.65	15.65	20.65	20.65
Farmington	Lower Collinsville Dam	Avon	60.3	Confluence Nepaug River	Hartland	76.3	29.8	41.9	29	33.4
Pequabuck	Middle Street Dam	Bristol	12.4	Middel Street Dam.	Bristol	15.9	3.1	3.1	9.3	9.3
Scantic	**Somersville Dam**	**Somers**	**25.6**	**Durkee Road**	**Somers**	**30.3**	**12.8**	**12.8**	**12.8**	**12.8**
Shetucket	**Willi-Natchaug conf.**	**Windham**	**28**	**Willi-Natchaug conf.**	**Windham**	**28**	**8.2**	**12.9**	**10.2**	**15.6**
Willimantic	**AmerThread Dam#1**	**Windham**	**1.2**	**AmerThread Dam#1**	**Windham**	**1.2**	**0**	**1.2**	**0**	**0**
Natchaug	**Willimantic Res Dam**	**Windham**	**4.2**	**Willimantic Reservoir**	**Windham**	**4.2**	**0**	**1.5**	**0**	**1.9**
Quinebaug	Aspinook Dam	Griswold	11.9	Cargill Falls	Putnam	57.5	9.8	21.2	2.1	36.3
Moosup	no run to mouth	n.a.	0	confluence w/Quanduck Bk	Sterling	14.5	0	7	0	7.5
totals			383.8			570.3	130.6	235.9	164.6	278.7

Table 5. Connecticut rivers that received transplanted American shad as part of the restoration effort.

River	Source of fish	Comments
Naugatuck	Connecticut River	Released above two dams
Quinnipiac	Connecticut River	Released above two dams
Mattabessett	Connecticut River	Released above one dam
Farmington	Connecticut River	Released above Rainbow Dam
Shetucket	Shetucket River	Fish from Greeneville Dam
Quinebaug	Shetucket River	Fish from Greeneville Dam

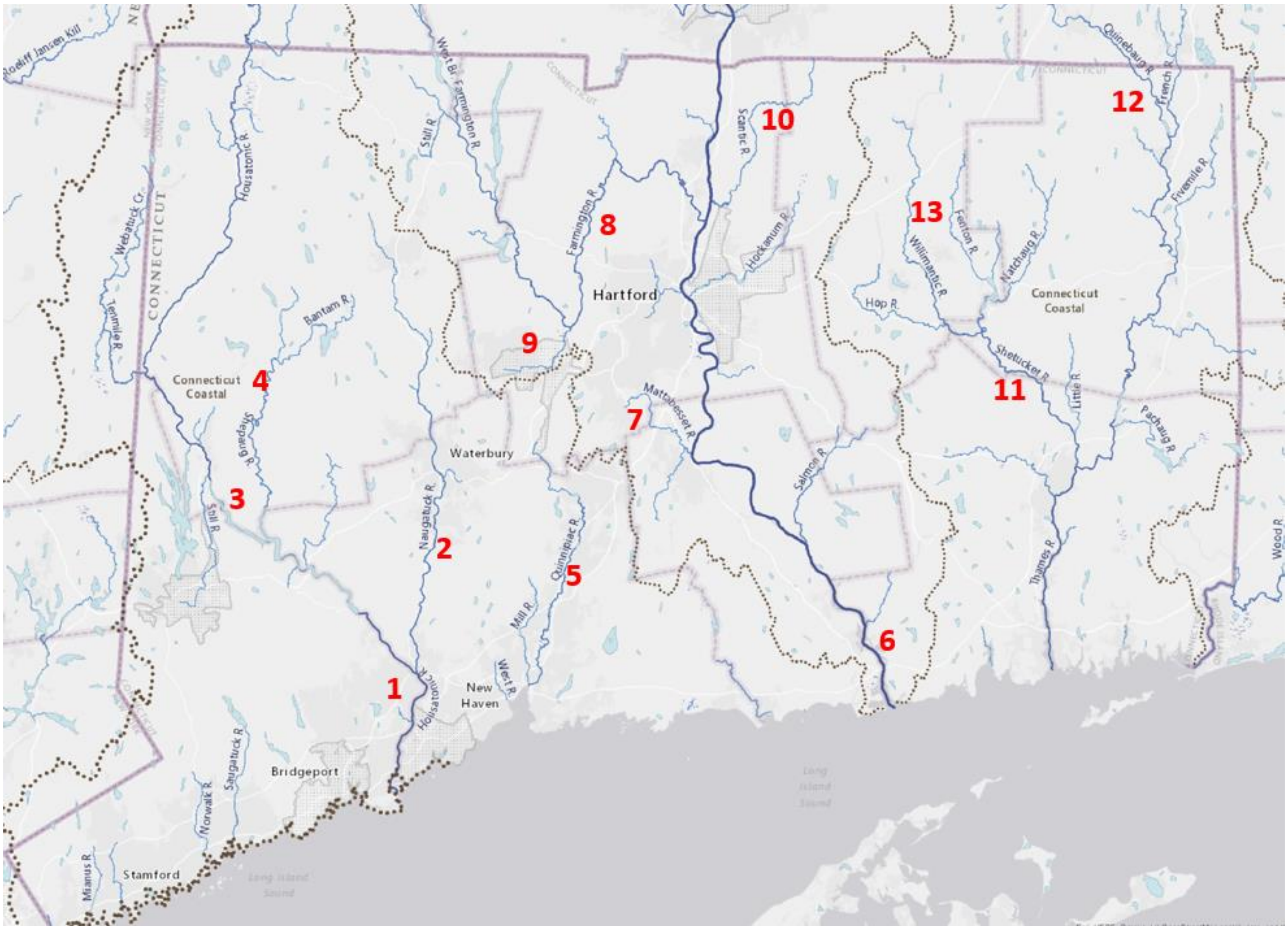
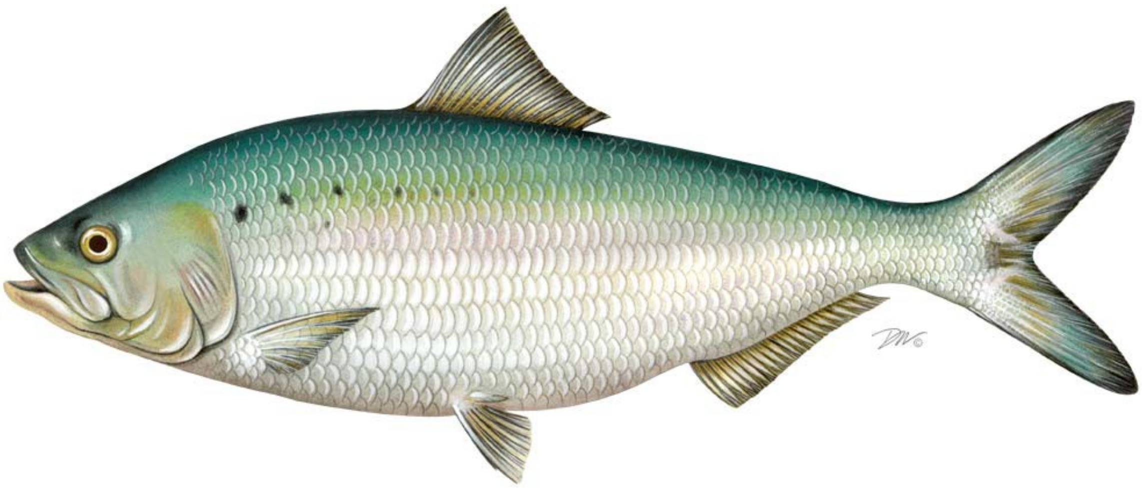


Figure 1. Map of existing runs of American shad, Connecticut. Numbers correspond to the numbers next to river names of existing runs (including those extended by fishways) in Table 1.

The Delaware River Basin Fish and Wildlife Management Cooperative

American Shad Habitat Plan for the Delaware River



Prepared by:
The Nature Conservancy for the Delaware River Basin Fish and Wildlife Management Cooperative

Submitted to the Atlantic States Marine Fisheries Commission as a requirement of Amendment 3 to the Interstate Management Plan for Shad and River Herring

American Shad Habitat Plan

for the Delaware River

Prepared by:

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for the

Delaware River Basin Fish & Wildlife Management Cooperative

Delaware Division of Fish and Wildlife • New Jersey Division of Fish and Wildlife • Pennsylvania Fish and Boat Commission • New York State Division of Fish, Wildlife and Marine Resources • U. S. Fish and Wildlife Service • National Marine Fisheries Service

For:

The Atlantic States Marine Fisheries Commission

Shad and River Herring Management Board

January 7, 2021

Members of the Delaware River Basin Fish and Wildlife Management Cooperative wish to express our deepest gratitude to Mari-Beth DeLucia and Lyndon DeSalvo of The Nature Conservancy. Simply stated, their exemplary contributions to the management of American Shad will form the foundation for the restoration of American Shad to the Delaware River Basin.

Thank you.

Introduction

The Atlantic States Marine Fisheries Commission's (ASMFC) Amendment 3 to the American Shad and River Herring Fishery Management Plan (FMP) requires all states to submit a Habitat Plan for American Shad stocks in their jurisdiction. This report contains specific information for the Delaware River and its tributaries as it relates to habitat for American Shad in New York, Pennsylvania, New Jersey, and Delaware and provides an update to the 2014 American Shad Habitat Plan (Plan) for the Delaware River Watershed.

Recognition of the need to improve water quality and conserve the valuable resources of the Delaware River Basin led to the formation of the Delaware River Basin Commission (DRBC) in 1961. The passage of the Clean Water Act in 1972, which established water quality standards to reduce municipal and industrial discharges, eventually led to improved water quality and the near elimination of the pollution block on the lower Delaware River. In 1978, two sections of the river covering 181 km (113 mi) were designated as National Wild and Scenic Rivers to be administered by the National Park Service (NPS): 117 km (73 mi) as the Upper Delaware Scenic and Recreational River, and 64 km (40 mi) as the Middle Delaware National Scenic and Recreational River. In year 2000, three additional sections of the mainstem river covering a total of 63 km (39 mi.) were designated the Lower Delaware Scenic and Recreational River, also administered by the National Park Service.

The Delaware River Basin Fish and Wildlife Management Cooperative (Co-Op) is responsible for the management of diadromous fishes inclusive of the American Shad. The Co-Op was established by Charter in 1973 and is comprised of U. S. Fish & Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), Delaware Department of Natural Resources and Environmental Control (DNREC), Pennsylvania Fish and Boat Commission (PFBC), Pennsylvania Game Commission (PGC), New York Division of Fish, Wildlife, and Marine Resources (NYDEC), and New Jersey Division of Fish and Wildlife (NJDFW). A coordinator from the USFWS serves as secretary to the Co-Op and acts as a liaison and technical specialist primarily on aquatic issues to the National Park Service (NPS), the DRBC, the Delaware Estuary Program, and the USFWS's Delaware Bay Estuary Project.

Signed into law in December 2016, the Delaware River Basin Conservation Act (Act) recognized the basin as "a natural treasure of great cultural, environmental, ecological, and economic importance" (H.R. 1772). The Act established the Delaware River Basin Restoration Program to support efforts to implement conservation, stewardship, and enhancement projects throughout the Delaware River Basin and has included funding for the conservation and restoration of fish and wildlife habitat. As of fiscal year (FY) 2020, over $20 million have been appropriated for the Delaware River Basin Conservation Act. The Nature Conservancy was awarded funding through this program to develop a restoration roadmap for American Shad and River Herring in the Delaware River Basin. Results from this project will inform future updates to this Plan, with an anticipated final report in 2021.

Background

The 531 kilometer-long (330 mile-long) Delaware River is unique along the Atlantic Coast in that it is free flowing along its entire length. It drains an area of 36,568 km^2 (14,119 mi^2) in four U.S. states: Delaware, New Jersey, New York, and Pennsylvania (Fig. 1). American Shad and other migratory fish have access to the entire mainstem river and far up into its headwaters where in other similar East Coast aquatic systems they have long been extirpated.

Figure 1: Delaware River and tributaries.

Historically, American Shad spawned throughout the main stem freshwater Delaware River and its tributaries as well as tributaries connected to the Delaware Bay (Stevenson 1899) (Fig 1). The location of the salt front would have determined the extent of the potential spawning habitat in the freshwater tidal section of the river in any given year. It was presumed that the principal spawning area prior to 1900 was located south of Philadelphia just above Gloucester, N.J. (rkm 157, rm 97) (U. S. Fish Commissioners, 1887; Cable, 1945; Walford, 1951; Mansueti and Kolb, 1953). Furthermore, the Howell family fishery, in existence for 200 years at Woodbury, N.J., kept catch records before 1830s documenting annual American Shad hauls of greater than 130,000 fish at rkm 150 (rm 93) (Harding 1999).

As early as the 1800s, exploitation, pollution, and dams in the upper Delaware River and tributaries were having a significant impact on the shad population in the Delaware. The construction of the extensive canals and locks in the late 1800s along the main stem Delaware, Lehigh, and Schuylkill rivers extirpated American Shad from historic spawning and nursery habitats. In 1828, a 16-ft dam was built across the Delaware River at Lackawaxen, PA. by the Delaware and Hudson Canal Company, remaining for approximately 80 years. Until dismantled, this dam decimated the upper river spawning run according to reports in the New York Times (NYT 1889). By the 1820s, fishermen noted the drastic decline in the size of shad and eight-pounders, which were once common, became hard to find by the early 1900s. As a result of exploitation and habitat loss, the shad fishery collapsed and led to the closure of the Gloucester fishery, which had been in existence for 200 years (Harding 1999)

During the 1940s and 1950s, heavy organic loading around Philadelphia caused severe declines in dissolved oxygen (D.O.) from late spring to early fall, blocking fish migrations through this area during this period (Hardy 1999). A remnant of the American Shad run in the Delaware River survived by migrating upstream early in the season, when water temperatures were low and flows were high, before the D.O. block set up. These fish that arrived earlier in the season migrated farther up the Delaware River to spawn. Out-migrating juveniles survived by moving downriver late in the season during high flows and low temperatures, thus avoiding the low oxygen waters present around Philadelphia earlier in the fall. During the 1960s, the Tri-State Shad Surveys as described by Chittenden (1976) showed that the greatest numbers of adults were captured from Minisink Island near Milford, Pa. (rkm 392) up to Skinners Falls near Narrowsburg, N.Y. (rkm 475); none were captured downstream from Manunka Chunk (rkm 325). Pollution continued to be a major factor until passage of the Federal Clean Water Act in 1972 and subsequent improvement to water quality in the 1980s.

Main Stem Habitat Assessment

Characterization of the spatial distribution of spawning and nursery habitats for American Shad within the non-tidal Delaware River is poorly understood. Presently, much of the non-tidal river above Trenton, N.J. supports high quality habitats (by current standards) and three quarters of this section of the Delaware River is included in the National Wild and Scenic Rivers System. Annual monitoring of spawning American Shad at Smithfield Beach (rkm 351, rm 218), spanning multiple decades (1996 – present), certainly indicate this reach supportive of spawning adults (DRBFWMC 2017). It is unknown if observations at Smithfield Beach are representative of the entire non-tidal river. Subsequent catches of young-of-the-year American Shad via annual beach seine monitoring throughout the non-tidal reaches suggests, at least, a broad spatial nursery habitat utilization of the non-tidal river reaches (DRBFWMC 2017). American Shad spawn primarily in the middle and upper Delaware mainstem spanning approximately 236 river kilometers (147 river miles) from near Easton, Pa. (rkm 296, rm 184) to Hancock, N.Y. (rkm 532, rm 330) (Chittenden 1976). . American Shad also appear to be using the lower non-tidal reaches and freshwater tidal reaches of the Delaware River with early life stages of shad present in the estuary (PSEG Nuclear, LLC 2018).

The tidal section of the river is densely populated and home to one of the largest freshwater ports in the world. Losses of freshwater tidal wetlands and other riparian habitat in this area are significant (Partnership for the Delaware Estuary 2017). However, overall water quality has been improving in recent years and the near elimination of the D. O. block has prompted initiation of potentially upgrading the Delaware Estuary designated use (DRBC 2015, 2020). Ichthyoplankton surveys completed in 2018 captured larval American Shad in all zones of the estuary from Trenton (rkm 214, rm 133) down to roughly rkm 56 (rm 35) and American Shad eggs from Trenton to the mouth of the Schuylkill River (rkm 149, rm 92) (PSEG Nuclear, LLC 2018).

Tributary Habitat Assessment

Historically, shad utilized many, if not all, medium to large tributaries for spawning in addition to the main stem habitat. Although the main stem Delaware River is free of physical barriers, many important tributaries that once supported large runs of American Shad are blocked or have reduced access and/or degraded habitat. In addition to legacy mill dams, the building of multiple canal systems (Delaware and Raritan, Lehigh Coal and Navigation, etc.) during the 19th century extirpated shad from many main stem tributaries. Many of these canal systems still preclude shad from utilizing historic spawning and nursery grounds.

Using historical and current information, a brief description of known historic and/or current status of spawning runs in all tributaries, as well as known habitat impacts can be found in Table 1: beginning in the headwaters and moving downstream. Figure 2 highlights the known spawning runs as of 2020.

A summary of the habitat status of major shad tributaries by state is below.

Table 1: Delaware River Tributaries with known current and/or historic American Shad spawning runs

Delaware River Tributaries	RKM	Historic (Pre-1950) Shad Run	Current Shad Run	Relevant Barriers	Comments	Data Sources
West Branch Delaware (NY)	532	Y (24km)	N	Cannonsville Dam (NY_119-2889)	Historic runs up to at least Deposit, NY. Cold tailwaters from NYC reservoirs create unsuitable conditions for shad.	Sykes & Lehman 1957; Bishop 1935; Gay 1892; Mansueti & Kolb 1953; Chittenden 1976
East Branch Delaware (NY)	532	Y (68km)	Y	Pepacton Dam (NY_146-1429)	Historic runs as far upstream as Downsville and within 30 miles of headwaters. Am. Shad present in East Branch during 1959-62 surveying and persist present day to East Branch, NY into the Beaver Kill. Cold tailwater from NYC reservoir and distance upstream probably varies with water temperatures.	Sykes & Lehman 1957; Bishop 1935; PA Fisheries Report 1896; PFBC Del River Mgmt Plan 2011;
Beaver Kill (NY)	East Branch Tributary	Y	Y (6km)	None	Chittenden (1976) reported shad 6km up Beaver Kill; and others reported shad 1km up Little Beaver Kill (tributary). Excellent water quality and undammed on its mainstem.	Chittenden 1976; Bishop 1935;
Lackawaxen River (PA)	447	Y	Y	Woolen Mill Dam (PA_64-053); Lake Wallenpaupack Dam (PA_52-051)	Thousands of shad noted in Lackawaxen in 1891 following installation of fishway at Lackawaxen Dam, as far as 25-30 miles above dam. Current fishing log mentions shad throughout Pike County section of Lackawaxen - likely a minor run today. Flow alteration due to releases from Lake Wallenpaupack that create cold tailwaters unsuitable for shad.	Gay 1892; Co-Op Fishways Review 1985; http://www.angelfire.com/pa/pikesportsmen/pcfsc4.1.htm; https://riverreporter.com/stories/loving-the-lackwaxen,18155
Mongaup River (NY)	420	Y	Y (7.5km)	Rio Dam (NY_149-0086); Mongaup Falls Dam (NY_148-0130)	Hydroelectric dams (currently in process of relicensing for 2022). Supports minor run in lower reach below Rio Dam. Mongaup Falls was almost certainly a natural barrier prior to hydroelectric dams. Estimated 237 Am. Shad were counted during American eel surveying in 2018.	Eagle Creek RE relicensing report 2020; National Park Service (Jessica Newbern - pers. comm.)

Neversink River (NY)	408	Y	Y (24km)	None	Small seine fishery in early 1800s. All historic mainstream habitat accessible and shad spawning run confirmed. Cuddebackville Dam removed in 2004 at RKM 16. High quality habitat.	Academy of Natural Sciences 2008 Neversink Shad Study; Gumaer 1890; The Nature Conservancy
Flat Brook (NJ)	362	Y (10km)	?	None	Minor historic run.	NJ Outdoors 1961
Brodhead Creek (PA)	343	?	Y	Brodhead Creek Dam (PA_1195188); Mill Creek Rd Dam in East Stroudsburg; McMichael Creek Mill Dam (PA_45-029)	Current fishing logs mention shad in lower reaches. Brodhead Creek Dam is breached and shad able to pass upstream to Mill Creek Rd Dam in East Stroudsburg. Exceptional water quality; prone to flooding.	http://www.paflyfish.com/forums/Open-Forums/Warm-Water---Salt-Water-Fly-Fishing/Shad-on-the-Brodhead/16,46369.html
Paulins Kill (NJ)	333	Y	Y (16km)	Paulina Lake Dam (NJ_NJ00170); County Line Dam (NJ_21-33)	Historic shad run documented in 1700s prior to damming of river. Current shad run up to Paulina Lake dam following removal of Columbia Lake Dam in 2018. TNC and partners looking to remove next two dams, the Paulina Lake and County Line.	NJ Freshwater Fisheries Report 2019; The Nature Conservancy; Cummings 1964
Pequest River (NJ)	318	?	Y	E.R. Collins & Sons Dam (NJ_24-28); E.R. Collins & Sons Dam (NJ_24-29); No Name Dam (NJ_24-31); Cedar Grove Dam (NJ_24-32)	Shad are in lower Pequest near confluence with Delaware River. Lower dams in Belvidere block shad and cause flooding issues.	https://www.nj.gov/dep/newsrel/2005/05_0061.htm
Lehigh River (PA)	295	Y (58km+)	Y (38km)	Easton Dam (PA_48-012); Chain Dam (PA_48-013); Hamilton Street Dam (PA_39-009); Cementon Dam (PA_39-060); Francis E. Walter Dam (PA_PA00008)	Historic fisheries with large run prior to construction of dams and canals. Current shad distribution possible to Cementon Dam (38km) where there is no fish passage. Lower three dams have fishways, but they are ineffective. Additional habitat impacts include lack of riparian vegetation (lower section); sediment deposition (lower section); metal contaminants. Easton averaged 1,459 shad passing fish ladder from 2004-2018 (Post 2012 data is estimated from electro-fishing below dam). Shad juveniles present.	2012 PFBC Next Steps in American Shad Restoration in PA; 2007 PFBC Lehigh River Management Plan; PFBC

Musconetcong River (NJ)	281	?	Y (9.5km)	Warren Mill Dam (NJ_NJ00765); Bloomsbury Dam (NJ_24-6); Asbury Mill Dam (NJ_NJ00581); Beattys Mill Dam (NJ_24-36)	Five dams removed between 2008-2016 by Musconetcong Watershed Partnership. Support from state and dam owner for removal of Warren Mill Dam, which has been reported as a safety hazard since 1981 and has shad at base. Cost of ~$20M to remove due to sediment buildup behind dam. Upstream designated as Wild and Scenic River.	https://www.state.nj.us/dep/nrr/restoration/bloomsbury-dam.html; USFWS (Danielle Mcculloch - pers. comm.);
Crosswicks Creek (NJ)	206	Y	Y	Gropp Lake Dam (NJ_NJ00235); Walnford Dam (NJ_28-21); Yardville Dam (NJ_28-15)	Crosswicks was clear for fish passage in mainstem in late 1800s. Creek is generally in good condition. Shad run is in lower section of river and confirmed at Route 206 in 2007.	Zich 1978; Fowler 1900; NJDEP 2012;
Blacks Creek (NJ)	206	Y	Y	Dunns Mill Dam (NJ_28-11)	Shad confirmed at West Burlington St in 2007.	NJDEP 2012;
Assiscunk Creek (NJ)	191	Y	Y	None	Water quality generally good and no dams evident in watershed. Shad confirmed at Rt 130 in 2004.	Zich 1978; NJDEP 2005, 2012;
Neshaminy Creek (PA)	186	Y	Y	Hulmeville Park Dam (PA_09-084); Neshaminy Falls Dam (PA_09-003; Spring Garden (PA_09-083); Neshaminy Weir Dam (PA_09-167)	Gay 1892 writes that shad frequent this stream. Shad run up to base of Hulmeville Park Dam and spawn in lower section of river. YOY shad documented in 2014 and 2017. Creek is susceptible to flooding, sewage discharge, and sediment and nutrient loading.	Gay 1892; Coop Fishways Review 1985; PFBC Darby + Neshaminy LMB Survey 2014; PFBC (Tyler Grabowski, John Buzzar - pers. comm.)
Rancocas Creek (NJ)	179	Y (25km+)	Y (2014)	Mill Dam (NJ00540); Smithville Dam (NJ_NJ00043); Cedar Lake Dam (NJ_31-13); Vincentown Mill Dam (NJ_NJ00396); Kirbys Mill Dam (NJ_NJ00634)	Listed as good shad river in 1896 PA Fisheries Report with runs 15-20 miles up. Shad in Rancocas between Centerton and Rancocas Park around 1950. Largest watershed in south central NJ. 2013 and 2014 NJ DEP Freshwater Fisheries seine samples found juvenile shad in Rancocas. Mill Dam at Mt Holly is impassable.	NJDEP; PA Fisheries Report 1896; Mansueti & Kolb 1953;
Pennsauken Creek (NJ)	169	?	Y	Moorestown Dam (NJ_NJ00635)	Small watershed with impacts from nutrients, PCBs.	NJDEP 2012
Cooper River (NJ)	163	Y	Y	Cooper River Parkway (Kaighn Ave) Dam (NJ_NJ00393); Cooper River Lake Dam (Cuthbert Ave); Wallworth Pond Dam (NJ_31-58); Evans Pond Dam (NJ_NJ00394)	Listed as good shad river in 1896 PA Fisheries Report. Fish ladder at Cooper River Lake with confirmed shad.	Zich 1978; NJFW 2012; PA Fisheries Report 1896; NJ F&W (Brian Neilan - pers. comm.)

Big Timber Creek (NJ)	154	Y (25km+)	Y	Blackwood Lake Dam (NJ_NJ00800); Laurel Springs Dam (NJ_NJ00400)	Listed as great shad river in 1896 PA Fisheries Report with runs 15-20 miles up and fisheries.10,400 shad yield in 1896. Historic water quality issues, development, Tidal Gate at Glendora. No dams before split into South and North branches.	Zich 1978; Fowler 1900; NJDEP 2012; PA Fisheries Report 1896; Stevenson 1898; NJDEP (Brian Neilan - pers. comm.)
Schuylkill River (PA)	149	Y (193km+)	Y (120km)	Fairmount Dam (PA_51-002); Flat Rock Dam (PA_PA00896); Norristown Dam (PA_46-001); Black Rock Dam (PA_46_027) - *all have fish passage however passage only currently monitored at Fairmount;* New Kernsville Dam (PA_PA00723); Auburn Dam (PA_PA00670)	Shad historically migrated 193km up the Schuylkill to Pottsville, PA and the river was estimated to support historic runs in the hundreds of thousands. Passage issues at lower four dams with fishways. Documented passage at Fairmount averaged1,460 annually between 2009-2019, with flooding or mechanical breakdowns in certain years serving to lower the average. Invasive species (Flathead Catfish; Northern Snakeheads) prey on migrating Alosines below Fairmount Dam. Single digit passage of shad at Black Rock Dam (2011-18). Juvenile shad present.	2018 Del R Shad & RH Compliance Report; 2012 PFBC Next Steps in American Shad Restoration in PA; 1985 Co-Op Fishways Review; PFBC (Ben Lorson, Josh Tryninewski - pers. comm.); PWD (Joe Perillo - pers. comm.)
Wissahickon Creek (PA)	Schuylkill Tributary	Y (Ambler, PA)	N	Grant Street Dam (PA_51-019); Robeson-Vandaren Mill Upper (PA_51-018)	History of Ambler document notes shad fishing as far as Ambler, PA. Habitat impacts include elevated nutrients, siltation, low DO, oil & grease, pathogens, non-native and invasive riparian species. Two dams right near confluence with Schuylkill. Flooding an issue.	2002 study; 2010 Wissahickon Creek Feasibility Study; Early History of Ambler, 1682-1888
Perkiomen Creek (PA)	Schuylkill Tributary	Y	?	Wetherill Dam (PA_46-050); Indian Head Dam (PA_46-051)	Historic fishery located at mouth of Perkiomen Creek. Wetherill Dam used for water supply and is barrier to passage.	PA Fisheries Report 1896;
Pickering Creek (PA)	Schuylkill Tributary	Y	N	Pickering Creek Dam (PA_1194555)	Fishery at mouth of Pickering Creek in 1730s. Pickering Creek Dam (water supply) completely cuts off watershed.	PA Fisheries Report 1896;
French Creek (PA)	Schuylkill Tributary	Y	?	Phoenixville Dam (PA_15-200)	Shad fishery mentioned in 1896 PA Fisheries report.	PA Fisheries Report 1896;
Woodbury Creek (NJ)	147	Y	N	Woodbury Creek Dam (NJ_NJ00398) - *has fish passage*	Listed as good shad river in 1896 PA Fisheries Report. Lowermost dam has fish ladder. Smaller watershed.	Zich 1978; NJDEP 2012; PA Fisheries Report 1896;
Mantua Creek (NJ)	144	Y	Y	Bethel Lake Dam (NJ_NJ00406)	2,000 shad reported in 1896; Zich confirmed them in Mount Royal in lower section of Mantua Creek. Shad occupy lower part of river.	Zich 1978, Fowler 1900; NJDEP 2012; Stevenson 1898;

Darby Creek (PA)	138	?	Y*	None	Barriers have been removed. Northern Snakeheads present in Darby. Shad found at 84th St Bridge in John Heinz National Wildlife Refuge in 2010. *Likely minor/limited to lower part.	PFBC Darby and Neshaminy Survey 2014; PFBC (Mike Kauffman, John Buzzar - pers. comm.); NOAA 2014;
Chester Creek (PA)	133.5	Y	Y	Rockdale Dam (PA_23-004); Llewellen Mill Dam (PA_23-012); Cotton Mill Dam (PA_1209034); Lenni Dam (PA_1194411)	Shad noted as plentiful in account from 1683. 2007/2008 PFBC Surveys: numerous American Shad fingerlings, one striped bass fingerling, and blue crabs in Chester Creek. American Shad utilize the Chester/Upland portion of Chester Creek as nursery water. Chester Creek had been previously unknown as American Shad nursery water.	PA Fisheries Report 1896; PA Fish and Boast Commission 2007-2008 Fisheries Report: https://pfbc.pa.gov/images/fisheries/afm/2008/6x09_08wwcw.htm
Repaupo Creek (NJ)	132.5	Y	?	Warrington Mill Dam (NJ_NJ00114)	Shown as historic run in 1985 Coop Fishways Report. Flood gate at mouth.	1985 Co-Op Fishways Review;
Raccoon Creek (NJ)	128	Y	Y	Mullica Hill Pond Dam (NJ_NJ00639) - *has fish passage*	Historic shad fishery, with 4,800 shad reported in 1896. American Shad confirmed at Rt 130 in 1994.	Zich 1978, Fowler 1900; NJDEP 2012; PA Fisheries Report 1896; Stevenson 1898;
Oldmans Creek (NJ)	122	Y	N	Harrisonville Dam (NJ_NJ00105)	Listed as good shad river in 1896 PA Fisheries Report. No shad found in recent sampling.	Zich 1978; NJDEP 2012; PA Fisheries Report 1896;
Christina River (DE)	113	Y	Y	Christina Lake Dam (DE_18); *aka Smalleys Pond Dam*; Cooch's Mill Dam (DE_24)	Historic fisheries, with 2,900 shad in 1896. Haul seine sampling in 2019 produced 21 American Shad in Christina River. Dams in key tributaries to Christina, and at Smalleys Pond (though shallow reaches below the spillway are presumed impassable by shad). Juvenile shad present.	DNREC 2019;
Brandywine Creek (DE)	Christina Tributary	Y	Y	Broom Street Dam (DE_13); Dam #3/O'Neill (DE_12); Alapocas Run Park Dam (DE_11); Brandywine Falls Dam (DE_10); DuPont Dam (DE_8/DE_9); Breck's Mill/Walker's Mill Dam (DE_7); Lower Hagley Dam (DE_6); Upper Hagley Dam (DE_emadd02); Eleutherian Dam (DE_5); Brandywine Creek/Rocklands Mill Dam (DE_101)	Historically supported very large shad runs. YOY shad were first found downstream of West St. dam (#1) on Brandywine Creek in 2017, when 386 YOY were sampled. Following West St. dam removal, YOY shad were found below Broom Street Dam (#2) in 2020 sampling. Dam removals and fishways planned for remaining 10 dams. Algal buildup due to dams.	DNREC 2019; Gay 1892; Brandywine Shad 2020 (pers. comm.)

White Clay Creek (DE)	Christina Tributary	Y	Y (6.5km)	Red Mill Dam (DE_23); Karpinski Park Dam (DE_emadd05); Paper Mill Dam (DE_22); Newark Intake Dam (DE_emadd06); Creek Road Dam (DE_emadd07); Deerfield Dam (DE_emadd08); White Clay Creek Preserve (PA_15-377)	Historic shad run. Byrnes Mill Dam removed in 2014 but reports that shallow depths and sediment might still impede fish passage here, especially during low tides. No shad present between removed Byrnes Mill Dam and existing Red Mill Dam in 2016+2017 during sampling. Dam removals and fishways planned for next four dams, with high potential for improving passage. Virtually the entire White Clay Creek watershed (306 km = 190 miles of streams) protected under the Wild & Scenic Rivers Act (since 2000).	DNREC 2019; Shad Restoration White Clay Creek 2010; DNREC (Mike Stangl - pers. comm.)
Salem River (NJ)	94	Y	N?	Flood gates.	Listed as good shad river, with 8,000 shad in 1896. Multiple flood gates near confluence with Delaware.	Zich 1978; NJFW 2012; Stevenson 1898; PA Fisheries Report 1896;
Alloway Creek (NJ)	87	Y	N?	Alloway Lake Dam (NJ_NJ00038), Elkinton Pond Dam (NJ_NJ00102)	300 shad yield in 1896.	Zich 1978; NJDEP 2012; Stevenson 1898;
Appoquinimink River (DE)	82	Y	?	Noxontown Pond Dam (DE_36); Silver Lake Dam (DE_35) - *have fish passage*	350 shad yield in 1896. Two YOY American shad were caught in Appoquinimink in 2017 approximately 1.2 km downriver of the Appoquinimink spillway. No shad reported in fish ladders, but Steeppass design is intended for river herring. Water quality: DO, nutrients.	DNREC 2020; DNREC (Mike Stangl - pers. comm.)
Blackbird Creek (DE)	81	Y	N?	Blackbird Pond Dam (DE_38)	Current status unknown. Water quality: DO, nutrients	
Duck Creek / Smyrna River (DE)	72	Y	N?	Duck Creek Pond (DE_40), Lake Como Dam (DE_41)	Current Status unknown. Fisheries on Duck Creek at Smyrna and Walker in 1896 yielded 1,500 shad. Water quality: DO, nutrients	Stevenson 1899;
Cohansey Creek (NJ)	61	Y	N?	Sunset Lake Dam (NJ_NJ00063) - *has fish passage;* Seeley's Mill Pond Dam (NJ_NJ00065)	Cohansey used to be third largest shad fishery in the state, after Hudson and Delaware. 21,850 shad yield in 1896. No current shad run.	1872 Fish Commissioners Report, Zichs 1978, ASMFC RH Stock Assessment 2017, Stevenson 1898; Brian Neilan (pers. comm.)
Leipsic River (DE)	55	Y	N?	Garrisons Lake Dam (DE_43) - *has fish passage*, Masseys Mill Pond Dam (DE_42)	Current status unknown. Fisheries from mouth to city of Leipsic yielded about 3,000 shad in 1896. Water quality: nutrients DO. No shad recorded at Garrisons Lake Dam, but fish ladder is steeppass designed for river herring.	DNREC 2020; Stevenson 1899;
Little River (DE)	45	Y	?	None	Current status unknown. Considered an important shad stream in 1940s. Undammed.	

St. Jones River (DE)	38	Y	Y*	Silver Lake Dam (DE_45); Moores Lake Dam (DE_47) - *have fish passage*	Fisheries in 1896 at Lebanon, Cherrytree Landing, and Dover took about 3,000 shad. In 2012, 2 American shad were found in in steeppass fish ladder at Moores Lake, designed for passing river herring. Water quality: nutrients, DO.	DNREC 2020; Stevenson 1899;
Murderkill River (DE)	37	Y	N?	Courseys Pond Dam (DE_54); McColleys Pond Dam (DE_55); McGinnis Pond Dam (DE_51) - *have fish passage*	Fisheries at Fredericka in 1896 yielded 8,700 shad. Current status unknown, but no shad recorded at steeppass fish ladders designed for river herring. Water quality: nutrients, DO.	DNREC 2020; Stevenson 1899;
Maurice River (NJ)	34	Y	Y	Union Lake Dam (NJ_NJ00448); Willow Grove Dam (NJ_NJ00040); Rainbow Lake Dam (NJ_NJ00751) - *have fish passage*	Historically supported extensive shad fisheries. Current status unclear - juveniles caught in seine 2013-15, but none in 2016. Shad believed to be present in lower section of river. Union Lake Dam has fish passage but is ineffective at passing alosines. Approximately 35 miles protected under the Wild & Scenic Rivers act (since 1993).	NJDEP 2012; 2019 Del Riv Basin Shad and RH Compliance Report; NJDEP (Brian Neilan - pers. comm.)
Mispillion River (DE)	19	Y	N?	Silver Lake Dam (DE_61) - *has fish passage;* Haven Lake Dam (DE_60); Marshall Millpond Dam (DE_62)	Current Status Unknown. Shad fishery in 1896 at and around Milford, DE yielded 50,000 shad. Water quality: nutrients, DO. No shad found at Silver Lake, but fish ladder is steeppass designed for river herring..	DNREC 2020; Stevenson 1899;
Broadkill River (DE)	0	Y	Y*	Wagamons Pond Dam (DE_69) - *has fish passage;* Diamond Pond Dam (DE_68); Red Mill Pond Dam (DE_71)	Shad were not present before being stocked here in 1880s (Stevenson 1899). *No shad in recent samples, but anglers reported American shad in Wagamons Pond spillway in 1998. Wagamons Pond fish ladder is steeppass designed for river herring. Water quality: DO, nutrients.	DNREC, 2020; Stevenson 1899; Mansueti & Kolb 1953; Jones 1999

Figure 2. Current American Shad runs in the Delaware River basin (as of 2020).

New York

The major spawning tributaries for shad in New York were the East and West Branches of the Delaware and the Neversink River. Most of the East and West Branches of the Delaware no longer support shad spawning runs due to the cold-water releases from the New York City reservoirs and direct loss of habitat due to the reservoirs themselves (Chittenden 1976). Fishways on these dams were deemed to be impractical due to the limited potential spawning areas above the reservoirs and the anticipated high cost of construction (DRBFWMC 1985). Shad historically migrated 68 km (42 miles) up the East Branch to the former town of Shavertown (Bishop 1936), which is now submerged beneath New York City's Pepacton Reservoir. There have been reports from fishermen of shad as far as 25 km (15.5 mi) up the East Branch, to the confluence with the Beaver Kill (Saunter 2001). Chittenden (1976) reported that shad ran 6 km (3.7 mi) up the Beaver Kill, an East Branch tributary, but it is unclear whether they spawn there. Other reports have shad going as far as a mile up into the Little Beaver Kill, a tributary of the Beaver Kill (McPhee 2005).

In the early 1800s, the shad run in the Neversink River was large enough to support a seine fishery in the lower part of the river and it is believed that shad went upstream approximately 24km (15 miles) to the Neversink Gorge, which is the natural barrier due to gradient on this river (Gumaer 1890). Following the removal of the Southwest Cuddebackville Dam in 2004, shad now have access to their full historic habitat in the Neversink River and are not impacted by cold-water releases from the Neversink Reservoir due to the large distance from the reservoir.

The lower section of the Mongaup River also supports a current shad run to the base of the Rio Dam. Located 7.4 rkm (4.6 rm) upstream of the confluence with the Delaware River, Rio Dam is the lowermost of three hydroelectric dams owned and operated by Eagle Creek Renewable Energy. Mongaup Falls Dam is approximately 7 rkm (4.5 rm) further upstream and the falls, now submerged, were almost certainly a natural barrier for American Shad prior to the development of the hydroelectric dams in the 1920s.

Pennsylvania

Two of the largest shad spawning tributaries in the Delaware River Basin are wholly located within Pennsylvania; the Schuylkill River has a drainage area of 5,180 km^2 and the Lehigh River has a drainage area of 3,484 km^2. The Schuylkill River is the largest tributary to the Delaware River with a point of entry at 149 rkm in the upper tidal estuary, in Philadelphia. Shad historically migrated 193 km (120 miles) upstream to Pottsville, Pa. and the runs were estimated to be in the hundreds of thousands. In 1820, the Fairmount Dam was constructed nine miles from the mouth of the Schuylkill River, effectively eliminating shad runs in the tributary for 150 years. In the last two decades, several main stem dams have been removed and others have added fish passage, which has theoretically enabled access to the New Kernsville Dam (rkm 160), though the current run is only estimated to Reading, Pa (rkm 120).

Located upriver in the non-tidal reach of the Delaware River, the Lehigh River enters the Delaware River at Easton, Pa. (rkm 294). Prior to the construction of a series of dams for supporting the Lehigh Coal and Navigation Canal system in the early 1800s, shad migrated at least 58 km (36 miles) upriver to Palmerton, Pa. where native Lenape Indians annually harvested shad at the confluence of the Aquashicola Creek. Although no written record has been found documenting the occurrence of shad further upriver of Palmerton, Pa., it is reasonable to assume they continued their migrations for some distance upriver. Construction of the Easton Dam (0 rkm) in 1829, at the confluence of the Lehigh and Delaware rivers, extirpated shad from the Lehigh River basin for 165 years until the subsequent installation of a fishway in 1994. Shad currently have access to the Cementon (Northampton) Dam at rkm 38, though ineffective passage at the three downstream dams limits the run size. In addition to physical barriers, water quality is also an issue in the Lehigh River due to impacts from several large municipalities that have discharges to the drainage and historic inputs from a former metal smelting operation.

At rkm 447, the Lackawaxen River was also a historically significant shad tributary and is believed to have a current run, according to anecdotal accounts from fishermen. Presently, Brookfield Energy is required to maintain an experimental trout tailwater via reservoir releases from Lake Wallenpaupack, as per FERC re-license agreement (FERC Proj. # 487, May 19, 2004). The target reach is from Kimbles Road Bridge (rkm 16, rm 10) down river to Rowland Road Bridge (rkm 6.4, rm 4). The program seeks, to prevent maximum instantaneous temperatures from exceeded 23.8 ºC (75 ºF) under most meteorological and hydrological conditions, and to prevent instantaneous stream temperatures from exceeding 25.0 ºC (77 ºF) during more severe meteorological and hydrological events. Annual performance evaluations indicated tailwater temperatures tended to vary but remain more characteristic of a transitional thermal habitat (> 21.1 ºC (70 ºF)) rather than reflective of a well-defined cold-water thermal habitat (< 18.8 ºC (66 ºF)). Efficacy of this program is anticipated to be evaluated in 2023.

Several other tributaries to the Delaware River within Pennsylvania are also known to have American Shad runs. Recent sampling in the Chester and Neshaminy Creeks have confirmed American Shad fingerlings in these tributaries and both are known to support nurseries in their lower reaches. Since American Shad were documented in the Darby Creek (rkm 138) within the John Heinz National Wildlife Refuge at Tinicum in 2010, four dams have been removed in the lower portion of the waterway enabling access to over 10 miles that were previously blocked (John Buzzar, pers. comm.).

New Jersey

In New Jersey, most tributaries that were tidally influenced had runs of American Shad that could support fisheries. In 1896, the Cohansey River (rkm 61) ranked third in New Jersey as a shad-producing stream, surpassed only by the Hudson and Delaware rivers, and shad were known to run 20 miles upstream to Bridgeton (Stevenson 1899). The Maurice River, which discharges into the Delaware Bay at rkm 34, similarly supported extensive shad fisheries until the construction of a dam at the present-day Union Lake in the 1860s. While the current Union Lake Dam does have a fish ladder, no shad have been documented passing here and they are recorded intermittently in the tidal Maurice River below the dam.

Several other tidal tributaries were also noted as supporting extensive shad runs at the end of the 19th century, including the Salem River (rkm 94), Oldmans Creek (rkm 122), Raccoon Creek (rkm 128), Woodbury Creek (rkm 147), Big Timber Creek (rkm 154), Cooper River (rkm 163), and Rancocas Creek (rkm 179) (PA State Commissioners of Fisheries 1896). In the Big Timber and the Rancocas creeks, shad were known to run 15 to 20 miles upstream and extended into the northern and southern branches of both these tributaries (PA State Commissioners of Fisheries

1896). An anadromous clupeid inventory by the New Jersey Division of Fish & Wildlife from 2002-2007 compiled previous run information and confirmed shad in many of these historically significant tributaries, though in large part their numbers and known extent have been greatly reduced. In these systems, shad face many habitat impacts including dams, canals, tidal gates, water quality, and predation by invasive species, particularly Flathead Catfish and Northern Snakeheads.

American Shad have also been confirmed in a few non-tidal New Jersey tributaries in recent years following dam removal and restoration efforts. With the removal of the lowermost barriers on the Paulins Kill and Musconetcong River, shad have begun occupying these systems and accessing newly available habitat. Currently, shad have access to 17 km of the Paulins Kill to the Paulina Lake Dam and 9 km of the Musconetcong River to the Warren Glen Dam. The lower reach of the Pequest River (rkm 318) near its confluence with the Delaware River is also documented to have shad present.

Delaware

In the late 1600s, the Christina watershed, including the White Clay and Brandywine creeks, supported tens of thousands of American Shad. However, as early as the 1700s, the Brandywine Lenape Native Americans were complaining to commissioners in Pennsylvania that dams were preventing the rockfish and shad from "coming up" as formerly and causing great injury to their people (Weslager 1989, Schutt 2007). The proliferation of dams and water pollution effectively eliminated the run in the watershed up until recently, when efforts to improve water quality and remove dams have succeeded in reopening previously inaccessible reaches within this system. In July 2020, sampling below Broom Street Dam (Dam #2) in Wilmington confirmed American Shad were spawning in this section that had been opened up with the removal of the West Street Dam in 2019. Shad are also known to access the Christina River beyond its confluence with the White Clay Creek and the White Clay to the former Byrnes Mill Dam site (DNREC 2020).

Historically, shad were found in most Delaware tributaries, with fisheries established in the Mispillion, Murderkill, St. Jones, Leipsic, and Smyrna Rivers (Mansueti and Kolb 1953, Stevenson 1899). The current status of shad in most of the tributaries that are found in State of Delaware is unknown, but few have been caught in any of these streams during the past century and it is unlikely that many of them currently support spawning runs. An eDNA study is planned for 2021 to assess presence of alosines, including American Shad, below Delaware fish ladders to better understand current distribution and the effectiveness of the steeppass ladders, which were designed to pass river herring. Dissolved oxygen and nutrient issues continue to impact many of these tributaries that once supported shad runs (DNREC 2005).

Nursery Habitat

Juvenile American Shad are presumed to remain in the rearing area of their natal river. It is unknown if juveniles remain fidel to a specific nursery reach or tend to disburse among suitable nursery habitats. Chittenden (1976) found the chief nursery in 1966 was apparently located upstream from Dingmans Ferry (rkm 385, rm 239) and was especially centered near Tusten, N.Y. and Lordville, N.Y. Subsequent annual beach seine monitoring by Co-Op members throughout the Delaware River support greatest catches typically occurring at Milford Beach (rkm 394) and Water Gap (rkm 339), but variation of site specific seine efficacy may also strongly dictate observed catch totals. Ross and Johnson (1997) found relatively general habitat use by juvenile shad in the mainstem upper Delaware River with some affinity for riffles and submerged aquatic vegetation (SAV); but no overall effect of habitat type on shad were determined (Ross et al. 1997), indicating that juveniles use a wide variety of habitat types to their advantage. Furthermore, the specific environmental and/or biological ques for outmigration are also poorly understood. Yet, it is generally accepted that juveniles out-migrate from nursery areas to marine waters during fall months as water temperatures decrease (Limburg et al. 2003).

In the upper Delaware River, prior to the construction of the New York City Delaware Reservoirs, Chittenden (1969) reported that juvenile shad were repeatedly captured in the West Branch of the Delaware River. In 1964 and 1966, after cold water releases began, Chittenden was unable to document juvenile shad in the West Branch. In other studies Miller (1975) and Chittenden (1972) both demonstrated that juvenile shad are adversely impacted by cold water releases in the West Branch and would abandon the affected areas. The East Branch is utilized as nursery habitat though the extent probably varies with temperature in any given year and warrants further study. Juvenile American Shad do not appear to be as tolerant to temperature changes as American Shad eggs and actively avoid temperature extremes, if possible. Laboratory tests suggest that juveniles can tolerate temperature increases between 1° and 4°C above ambient temperature, but beyond that they will avoid changes if given a choice (Moss 1970).

Historically the tidal Delaware River and Estuary were probably an important nursery area with thousands of acres of saltwater and freshwater tidal marshes of highly productive systems with extensive food and shelter for juvenile shad. More than 145,000 hectares of brackish and salt marshes remain in the Delaware Estuary, roughly half in Delaware and half in New Jersey. However, only five percent of freshwater tidal marshes in the Delaware River Basin remain (Kreeger et al. 2010). Concentrated between Wilmington, Del. and Trenton, N.J., the condition of these marshes reflects the effects of negative impacts of intensive land conversion and industrial activities in this urban corridor (Simpson et al. 1983). Residential and commercial development has left only fragments of freshwater tidal marsh fringing the freshwater tidal reaches of the Delaware River and its tributaries in this section of the basin.

Very little is known about nursery habitat in tributaries to the Delaware River. The continued extirpation of shad from various tributaries throughout the basin preclude understanding for their importance to American Shad, forcing inferences to be drawn from anecdotal historical references. However, observations upstream of recently removed barriers suggests that shad will return and utilize tributary habitat if unimpeded. For example, young-of-year shad were documented in 2020 upstream of the removed West Street Dam on the Brandywine Creek and are also known to utilize the main stem of the Christina River. In 2019 NJFW biologists documented the return of American Shad to the Paulins Kill after the removal 109-year-old Columbia Lake Dam (NJDEP 2019). In 2008, PFBC biologists have also documented that American Shad utilize the Chester/Upland portion of Chester Creek and lower section of Neshaminy Creek as nursery waters.

Threat Assessment

Despite significant improvements to water quality and fish passage in the Delaware River Basin over the last decade or more, there has been a lack of a corresponding rebound in numbers of American Shad. The 2020 ASMFC Stock Assessment for American Shad determined that adult mortality was unsustainable in the Delaware River population. An assessment of solely the threats to freshwater and brackish habitat is insufficient. A holistic approach to addressing the cumulative impacts of a variety of stressors is needed across all of this species' life cycles.

Barriers to Migration:

Although the Delaware River is free flowing along its mainstem, there are over 1,500 dams and other barriers on its tributaries that greatly impact aquatic connectivity throughout the basin. A list of barriers relevant to American Shad based on current and historic spawning runs is included here in Table 2.

Table 2. Relevant Barriers to American Shad migration in the Delaware River Basin.

Dam Name	Dam ID	Stream Name (NHD)	HUC-12 Name	Barrier Status	Fishway Type
Cannonsville Dam	NY_119-2889	West Branch Delaware River	Cannonsville Reservoir	Complete	
Pepacton Dam	NY_146-1429	East Branch Delaware River	Trout Brook-East Branch Delaware River	Complete	
Woolen Mill Dam	PA_64-053	Lackawaxen River	Belmont Lake-West Branch Lackawaxen River	Complete	
Lake Wallenpaupack	PA_52-051	Wallenpaupack Creek	Lake Wallenpaupack-Wallenpaupack Creek	Complete	
Rio Dam	NY_149-0086	Mongaup River	Rio Reservoir-Mongaup River	Complete	
Mongaup Falls Dam	NY_148-0130	Mongaup River	Rio Reservoir-Mongaup River	Complete	
Brodhead Creek Dam	PA_1195188	Brodhead Creek	Lower Brodhead Creek	Breached	
Mill Creek Road Dam	?	Brodhead Creek	Lower Brodhead Creek	Complete	
McMichael Creek Mill Dam	PA_45-029	McMichael Creek	Lower McMichael Creek	Complete	
Paulina Lake Dam	NJ_NJ00170	Paulins Kill	Middle Paulins Kill River	Complete (to be removed)	
County Line Dam	NJ_21-33	Paulins Kill	Middle Paulins Kill River	Complete (to be removed)	
E.R. Collins & Son Dam	NJ_24-28	Pequest River	Lower Pequest River	Complete	
E.R. Collins & Son Dam	NJ_24-29	Pequest River	Lower Pequest River	Complete	
No Name Dam	NJ_24-31	Pequest River	Lower Pequest River	Complete	
Cedar Grove Dam	NJ_24-32	Pequest River	Lower Pequest River	Complete	
Easton Dam	PA_48-012	Lehigh River	Lehigh River-Delaware River	Fishway	Vertical slot

Dam Name	Dam ID	Stream Name (NHD)	HUC-12 Name	Barrier Status	Fishway Type
Chain Dam	PA_48-013	Lehigh River	Lehigh River-Delaware River	Fishway	Vertical slot
Hamilton Street Dam	PA_39-009	Lehigh River	Lehigh River-Delaware River	Fishway	Vertical slot
Cementon Dam	PA_39-060	Lehigh River	Fireline Creek-Lehigh River	Complete	
Warren Mill Dam	NJ_NJ00765	Musconetcong River	Lower Musconetcong River	Complete (to be removed)	
Bloomsbury Graphite Dam	NJ_24-6	Musconetcong River	Lower Musconetcong River	Complete (to be removed)	
Asbury Mill Dam	NJ_NJ00581	Musconetcong River	Lower Musconetcong River	Complete	
Gropps Lake Dam	NJ_NJ00235	Back Brook	Lower Crosswicks Creek	Fishway	Steeppass*
Walnford Dam	NJ_28-21	Crosswicks Creek	Lower Crosswicks Creek	Unknown, assumed complete	
Yardville Dam	NJ_28-15	Doctors Creek	Doctors Creek	Unknown, assumed complete	
Dunns Mill Dam	NJ_28-11	Blacks Creek	Blacks Creek	Unknown, assumed complete	
Hulmeville Dam	PA_09-084	Neshaminy Creek	Core Creek-Neshaminy Creek	Complete	
Neshaminy Falls Dam	PA_09-003	Neshaminy Creek	Core Creek-Neshaminy Creek	Complete	
Spring Garden Dam	PA_09-083	Neshaminy Creek	Mill Creek-Neshaminy Creek	Complete	
Neshaminy Weir	PA_09-167	Neshaminy Creek	Mill Creek-Neshaminy Creek	Complete	
Mill Dam	NJ_NJ00540	North Branch Rancocas Creek	Powells Run-North Branch Rancocas Creek	Complete	
Smithville Dam	NJ_NJ00043	North Branch Rancocas Creek	Powells Run-North Branch Rancocas Creek	Fishway	Steeppass*
Cedar Lake Dam	NJ_31-13	South Branch Rancocas Creek	Jade Run-South Branch Rancocas Creek	Unknown, assumed complete	
Kirbys Mill Dam	NJ_NJ00634	SW Branch South Branch Rancocas Creek	Little Creek-Southwest Branch Rancocas Creek	Complete	
Vincentown Mill Dam	NJ_NJ00396	South Branch Rancocas Creek	Jade Run-South Branch Rancocas Creek	Fishway	Steeppass?
Moorestown Dam	NJ_NJ00635	North Branch Pennsauken Creek	Pennsauken Creek	Complete	
Cooper River Parkway (Kaighn Ave) Dam	NJ_NJ00393	Cooper River	Cooper River	Fishway	Flood gate
Cooper River Lake Dam (Cuthbert Ave)	?	Cooper River	Cooper River	Fishway	Flood gate
Wallworth Pond Dam	NJ_31-58	Cooper River	Cooper River	Fishway	Steeppass*
Evans Pond Dam	NJ_NJ00394	Cooper River	Cooper River	Fishway	Steeppass*
Laurel Springs Dam	NJ_NJ00400	North Branch Big Timber Creek	North Branch Big Timber Creek	Unknown, assumed complete	
Blackwood Lake Dam	NJ_NJ00800	South Branch Big Timber Creek	South Branch Big Timber Creek	Complete	
Fairmount Dam	PA_51-002	Schuylkill River	City of Philadelphia-Schuylkill River	Fishway	Vertical slot
Flat Rock Dam	PA_PA00896	Schuylkill River	Plymouth Creek-Schuylkill River	Fishway	Vertical slot
Norristown Dam	PA_46-001	Schuylkill River	Plymouth Creek-Schuylkill River	Fishway	Denil
Black Rock Dam	PA_46-027	Schuylkill River	Mingo Creek-Schuylkill River	Fishway	Denil
Kernsville Dam	PA_PA00723	Schuylkill River	Pigeon Creek-Schuylkill River	Complete (to be removed)	
Auburn Dam	PA_PA00670	Schuylkill River	Mahannon Creek-Schuylkill River	Complete	
Grant Street	PA_51-019	Wissahickon Creek	Lower Wissahickon Creek	Complete	
Robeson-Vandaren Mill Upper Dam	PA_51-018	Wissahickon Creek	Lower Wissahickon Creek	Complete	
Wetherill Dam	PA_46-050	Perkiomen Creek	Lower Perkiomen Creek	Complete	
Indian Head	PA_46-051	Perkiomen Creek	Lower Perkiomen Creek	Complete	
Pickering Creek Dam	PA_1194555	Pickering Creek	Pickering Creek	Complete	
Phoenixville Dam	PA_15-200	French Creek	Lower French Creek	Complete	
Woodbury Creek Dam	NJ_NJ00398	Woodbury Creek	Woodbury Creek	Fishway	Steeppass*

Dam Name	Dam ID	Stream Name (NHD)	HUC-12 Name	Barrier Status	Fishway Type
Bethel Lake Dam	NJ_NJ00406	Mantua Creek	Mantua Creek	Complete	
Rockdale Dam	PA_23-004	Chester Creek	Chester Creek	Complete	
Cotton Mill Dam	PA_1209034	Chester Creek	Chester Creek	Unknown, assumed complete	
Lenni Dam	PA_1194411	Chester Creek	Chester Creek	Unknown, assumed complete	
Warrington Mill Dam	NJ_NJ00114	Repaupo Creek	Repaupo Creek-Delaware River	Complete	
Mullica Hill Pond Dam	NJ_NJ00639	Raccoon Creek	Raccoon Creek	Fishway	Steeppass*
Harrisonville Dam	NJ_NJ00105	Oldmans Creek	Oldmans Creek-Delaware River	Complete	
Christiana Lake Dam	DE_18	Christina River	Middle Christina River	Complete	
Coochs Mill Dam	DE_24	Christina River	Upper Christina River	Unknown, assumed complete	
Broom Street Dam	DE_13	Brandywine Creek	Lower Brandywine Creek	Complete	
Dam #3 (O'Neill)	DE_12	Brandywine Creek	Lower Brandywine Creek	Breached	
Alapocas Run Park Dam	DE_11	Brandywine Creek	Lower Brandywine Creek	Breached	
Brandywine Falls Dam	DE_10	Brandywine Creek	Lower Brandywine Creek	Complete	
DuPont Dam	DE_9	Brandywine Creek	Lower Brandywine Creek	Breached	
DuPont Dam	DE_8	Brandywine Creek	Lower Brandywine Creek	Breached	
Breck's Mill/Walker's Mill Dam	DE_7	Brandywine Creek	Lower Brandywine Creek	Complete	
Lower Hagley Dam	DE_6	Brandywine Creek	Lower Brandywine Creek	Complete	
Upper Hagley Dam	DE_emadd02	Brandywine Creek	Lower Brandywine Creek	Breached	
Eleutherian Dam	DE_5	Brandywine Creek	Lower Brandywine Creek	Complete	
Brandywine Creek Dam	DE_101	Brandywine Creek	Middle Brandywine Creek	Breached	
Red Mill Dam	DE_23	White Clay Creek	Upper White Clay Creek	Complete (to be removed)	
Karpinski Park Dam	DE_emadd05	White Clay Creek	Upper White Clay Creek	Complete	
Paper Mill Dam	DE_22	White Clay Creek	Upper White Clay Creek	Complete (to be removed)	
Newark Intake Dam	DE_emadd06	White Clay Creek	Upper White Clay Creek	Complete	
Creek Road Dam	DE_emadd07	White Clay Creek	Upper White Clay Creek	Complete	
Deerfield Dam	DE_emadd08	White Clay Creek	Upper White Clay Creek	Complete	
White Clay Creek Preserve	PA_15-377	White Clay Creek	Upper White Clay Creek	Complete	
Alloway Lake Dam	NJ_NJ00038	Alloway Creek	Upper Alloway Creek	Fishway	Steeppass*
Elkinton Pond Dam	NJ_NJ00102	Deep Run	Upper Alloway Creek	Complete	
Noxontown Pond Dam	DE_36	Appoquinimink River	Drawyer Creek-Appoquinimink River	Fishway	Steeppass*
Silver Lake Dam	DE_35	Deep Creek	Drawyer Creek-Appoquinimink River	Fishway	Steeppass*
Blackbird Pond Dam	DE_38	Blackbird Creek	Blackbird Creek	Complete	
Duck Creek Pond Dam	DE_40	Smyrna River	Duck Creek	Complete	
Lake Como Dam	DE_41	Mill Creek	Duck Creek	Complete	
Sunset Lake Dam	NJ_NJ00063	Cohansey River	Middle Cohansey River	Fishway	Steeppass*
Seeleys Mill Pond Dam	NJ_NJ00065	Cohansey River	Upper Cohansey River	Unknown, assumed complete	
Garrisons Lake Dam	DE_43	Leipsic River	Upper Leipsic River	Fishway	Steeppass*
Masseys Mill Pond Dam	DE_42	Leipsic River	Upper Leipsic River	Complete	
Silver Lake Dam - Dover	DE_45	Saint Jones River	Upper Saint Jones River	Fishway	Steeppass*
Moores Lake Dam	DE_47	Isaac Branch	Isaac Branch	Fishway	Steeppass*
Courseys Pond Dam	DE_54	Murderkill River	Spring Branch-Murderkill River	Fishway	Steeppass*
McColleys Pond Dam	DE_55	Browns Branch	Browns Branch	Fishway	Steeppass*
McGinnis Pond Dam	DE_51	Hudson Branch	Spring Creek	Fishway	Steeppass*

Dam Name	Dam ID	Stream Name (NHD)	HUC-12 Name	Barrier Status	Fishway Type
Union Lake Dam	NJ_NJ00448	Maurice River	Union Lake-Maurice River	Fishway	Denil
Willow Grove Dam	NJ_NJ00040	Maurice River	Burnt Mill Branch-Maurice River	Fishway	Steeppass*
Rainbow Lake Dam	NJ_NJ00751	Muddy Run	Lower Muddy Run	Unknown, assumed complete	
Silver Lake Dam - Milford	DE_61	Mispillion River	Upper Mispillion River	Fishway	Steeppass*
Haven Lake Dam	DE_60	Mispillion River	Upper Mispillion River	Complete	
Marshall Millpond Dam	DE_62	Mispillion River	Middle Mispillion River	Complete	
Wagamons Pond Dam	DE_69	Broadkill River	Round Pole Branch-Broadkill River	Fishway	Steeppass*
Diamond Pond Dam	DE_68	Ingram Branch	Round Pole Branch-Broadkill River	Complete	
Red Mill Pond Dam	DE_71	Old Mill Creek/Martin Branch	Canary Creek-Broadkill River	Complete	

* Steeppass fish ladders in the State of Delaware are designed to pass river herring and not American Shad. American Shad are not able to effectively pass steeppass fishways greater than 20 m in length with a 27.3% slope (Slatick and Basham 1985)

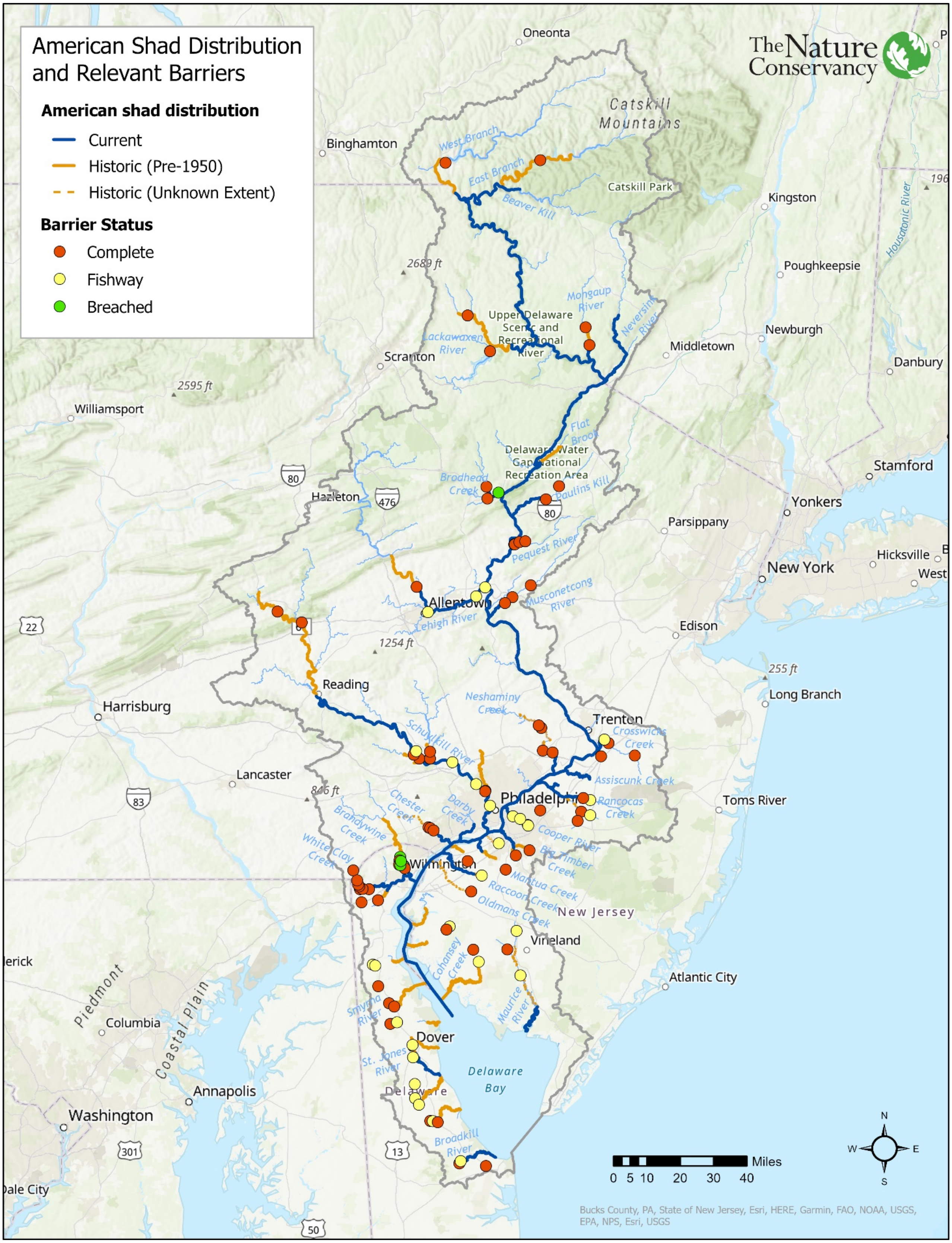

Figure 3. American Shad distribution and relevant barriers to migration in the Delaware River Basin.

Climate Change

Stream flow and temperature provide significant cues for shad migration and spawning in streams. Changes in the timing of peak spring flow have already been documented in the last 50 years (Frumhoff et al. 2007). A recent analysis of flow data in the upper Delaware River by Moberg et al. (2009) found that, at the Cooks Falls reference gauge on the Beaver Kill, the mean annual flow has increased from 532 to 597 cfs (12%) between the pre- and post-reservoir periods. Median monthly flows have increased in summer, fall, and winter months, and have decreased during spring months (March-June). Low and high flows, including 3-, 7-, and 30-day events, have increased by 4 to 54%. In general, the post-reservoir period was wetter than the pre-reservoir period, as represented by both monthly median flows and the magnitude of low and high flow events. This pattern is consistent with long-term climatic trends published by Burns et al. (2007).

Over their history, diadromous fish, in general, have shown to be resilient and adaptable to environmental changes and stressors. Large ranges, diverse habitats and extremely abundant populations account for this resilience (McDowall 2001). With the current status of American Shad stocks at historic lows, changes in flow, temperature, and extreme flooding are likely a more significant threat to the status of this species than if populations of shad were near historical abundances and if their full range of habitats were available. In the Delaware River Basin, the shad population should be managed in a way that promotes and protects a diverse age structure and habitat utilization. A population that utilizes the full extent of the main stem as well as numerous tributaries of different size classes may have greater reproductive potential to protect against negative impacts from environmental disturbances (Hillborn et al. 2003, Schindler et al. 2010). A diverse age structure and behavioral patterns within a population of migratory fish can help mitigate against stochastic or anthropomorphic effects and take advantage of ideal conditions for population recruitment (Kerr et al. 2010, Secor 2007).

Tropic dynamics/Invasive species

In the past, the American Shad in the Delaware River Basin coexisted with fewer types of predatory fish than occur today. Since the late 1800s, several species of piscivorous fish have been introduced and subsequently naturalized in the Delaware River Basin, including: Largemouth Bass, Walleye, Smallmouth Bass, Channel Catfish, Muskellunge, Rainbow Trout, and Brown Trout representing some of the most desirable present-day gamefishes. Others including Flathead Catfish, Northern Snakehead, and Asian Swamp Eels have also become established in parts of the watershed. Furthermore, confirmed separate angler catches of Blue Catfish (N = 1 in NJ; N = 1 in PA) in the freshwater reaches of the Delaware Estuary in 2020 is suggestive of their presence likely as initial migrants into the Delaware River Basin via the C&D Canal.

Presumed increased predation by the indigenous (e.g., Striped Bass, White Perch) and naturalized invasive piscivores may be having an adverse impact on the shad population. American Shad are broadcast spawners, using a predator saturation strategy for survival of eggs, larval and juveniles. The increased predation coupled with severely reduced habitat range, potentially reduce survivability to adults. While unquantifiable, as an interesting speculation, would an average year-class production observed in present day, have been considered poor production in pre-colonial times, prior to the introduction of invasive species and imposed habitat limitations? By extension, would present day exceptional juvenile production, have been considered average in pre-colonial times? The converse, however, is of paramount importance, to what extent of juvenile production is needed to surpass present day predator saturation to enable shad population growth? And can it be expected present day habitat availability be able to support the necessary numbers of juvenile shad?

This type of threat is difficult to address and highlights the importance in ecosystem-based management in fisheries. Future studies such as stomach analysis on naturalized non-native species and the development of ecosystem level fish population models are critical to understanding if shad populations are being impacted by abundant predator populations. Because the non-native piscivores have become widely established in the river system and prized by numerous groups of anglers, eradication of these species is unlikely.

Flow Alteration

River flows on the Delaware River have long been manipulated by the combined outflow from three New York City Delaware Reservoirs. Management of these reservoirs is linked to a 1954 U. S. Supreme Court Decree, which provides for the supply of up to 800 million gallons per day of water to the New York City metropolitan area (283 U.S. 805, 1954). The Decree stipulates the use of reservoir releases for maintaining a river flow objective of 1,750 cfs at Montague, NJ. Over the years since the 1954 Decree, reservoir releases have been managed through a series of evolving programs based on unanimous agreement by the Parties to the Decree (States of New Jersey, New York and Delaware, Commonwealth of Pennsylvania, and New York City).

The "Flexible Flow Management Program" (FFMP) is the current framework for managing diversions and releases from New York City's Delaware Reservoirs. This program was designed by the Parties to the Decree to support multiple flow management objectives, including water supply; drought mitigation; flood mitigation; protection of the tailwater fisheries; a diverse array of habitat needs in the mainstem, estuary and bay; recreational goals; and salinity repulsion in the Delaware Estuary related to maintaining adequate water quality for municipal water supply withdrawals from the estuary. Additionally, the FFMP was structured, in part, to provide a more natural flow regime and a more adaptive means than the previous operating regimes for managing releases and diversions from these reservoirs, inclusive of improved modeling tools.

Insight relative to the Delaware River Basin water management practices to aquatic community processes have been previously evaluated (DePhilip and Moberg 2013, TNC 2017). Findings were suggestive water management strongly influenced aquatic communities by mitigating seasonal flow regimes. The 2017 Flexible Flow Management Plan structure, in part, attempts to retain natural flow regimes to the greatest extent practical, while being supportive of recognized down basin objectives (FFMP 2017). The recent changes include a thermal mitigation protocol to allow for additional reservoir releases during periods of thermal stress, which has been instituted during the summers of 2019 and 2020. Yet, significant alteration of basin water supply sources usage has high likelihood capacity to diminish resiliency of ecological meso-habitat functionality. Over management of flowing systems can reduce or eliminate natural cues/habitat that aquatic organisms rely upon to complete various stages of their life cycles.

Within the upper Delaware River Basin, the New York City Delaware Reservoirs tailwaters are specifically managed for sustaining cold-water aquatic community. Managed tailwaters encompass the East and West Branches and the Delaware River down river to Callicoon, NY (rkm 487). Thus, American Shad are considered extirpated from the West Branch and upper reaches of the East Branch (above the Beaver Kill). Yet the Delaware River main stem reach, Hancock, NY (rkm 531) to Callicoon, NY, is considered transitional to warm-water aquatic communities. This designation is presumed to support the continuance of connectivity for American Shad spawning adults and YOY access to the lower reaches of the East Branch Delaware River where they are presently known to occur. The influences of the FFMP release management upon American Shad is encapsulated in the Decision Support System (DSS) and its successor the Riverine Environmental Flow Decision Support System (REFDSS) (Bovee et al. 2007). These are Habitat Suitability Index (HSI) models coupled with Instream Flow Incremental Methodology for evaluating flow regimes upon habitat availability in the upper Delaware River. This type of modeling capability has not been extended further down river for the remainder of the Delaware River.

Impingement and Entrainment

Nearly 10 percent of Americans rely on the waters of the Delaware River Basin for drinking and industrial use (DRBC 1998). Power generating facilities, refineries, and other industries rely on withdrawal of surface water from the Delaware River to cool their industrial processes, with most industrial water withdrawals requiring continuous once-through use of water. This withdrawal results in fish and other aquatic organisms either becoming trapped against the intake screens (impingement – I) or taken further into the cooling system (entrainment – E). Both I&E can result in the death of fish and other organisms. Larger individuals typically become impinged and smaller organisms such as eggs and larvae typically become entrained. Impingement does not necessarily result in 100% mortality of affected organisms, but entrainment is considered 100% lethal. When fish spawn in spring and early summer in the Delaware River, the resulting eggs and larvae are vulnerable to entrainment; as fish grow larger during the balance of the year, they become susceptible to impingement. Therefore, losses to I&E are ongoing throughout the calendar year.

There are several large water intake systems at energy projects on the Delaware River. The Co-Op acquired 316b reports for five companies with cooling water intake structures (CWIS) on the Delaware River or its tributaries plus Annual Biological Monitoring Reports for the Salem Generating Station. These reports indicated that individual projects can entrain millions of American Shad eggs and larvae annually and impinge tens of thousands of juveniles (J. Mohler pers. comm.). In a river system with numerous intake facilities that occur in spawning and nursery grounds for American Shad, the cumulative impacts to the population could be substantial.

Impingement data for other important fisheries suggest that impacts may be occurring on Striped Bass and Weakfish populations, reducing the number of fish that would later be available for recreational and commercial fishing. Recent estimates derived by staff from the DNREC, Division of Fish & Wildlife (DFW) suggest that losses of early life stages of Striped Bass translate into losses of Adult Equivalents that rivals or even exceeds current commercial and recreational harvest in Delaware (Ed Hale, DFW, pers. comm.). Losses of large numbers of forage species also reduce the food resources available in the river, further impacting fish communities in the Delaware

River. Reporting of I&E losses are inconsistent. Consistent periodical assessments would aid in providing a better characterization of loss to this type of mortality.

Restoration

Over the last decade, there have been increased efforts to restore access to historic habitat for American Shad via dam removal and improved fish passage throughout the Delaware River Basin. Multiple partnerships are actively seeking to address barriers in key tributaries, and, in some instances, shad have returned to newly accessible reaches of river within the first year. While the Delaware River population has not come close to previously set restoration targets, it is clear that shad will return to restored habitat if given the opportunity. This section offers a brief overview of recent restoration efforts across the basin and highlights upcoming dam removal projects (also noted in Table 2).

The PFBC has maintained an American Shad Restoration Program since 1985. The original intent of the program envisioned returning an annual self-sustaining, wild adult spawning runs into the Lehigh and Schuylkill rivers. After 35 years of restoration efforts, including improved fish passage and hatchery stocking programs, this has not materialized as expected, and the current runs are far below previous restoration targets. The Lehigh River shad spawning runs remain well below the original expectations of successfully passing 165,000 – 465,000 wild shad annually (PFBC 1988). Similarly, annual spawning runs into the Schuylkill River also fall well short of original restoration goal of an annual run size of 300,000 – 850,000 wild shad (PFBC 1988). It is important to note, however, that these estimates are based on historic runs and available habitat within each basin and do not account for the depressed American shad population across the Delaware River basin and along the entire Atlantic Coast.

Within the Lehigh River, the wild component has been increasing, best represented in 2015, with wild shad composed over two-thirds of the Lehigh River spawning run; whereas, returning shad into the Schuylkill River are mostly (> 95%) originating from hatchery stocked shad fry. Thus, the hatchery component remains integral to both river spawning runs.

It is the conclusion of PFBC, American Shad passage into the Lehigh and Schuylkill rivers are inefficient and inadequate to support the restoration of a self-sustaining population. Yet without maintenance fry shad stockings, any future spawning run into either tributary would most likely be nominal. The PFBC will continue maintenance shad fry stockings to encourage annual spawning runs in both tributaries. Yet, PFBC will also investigate the feasibility of alternative methodology for possibly increasing the magnitude of annual hatchery stockings.

The Schuylkill River is the largest tributary to the Delaware River and historically supported American Shad runs in the hundreds of thousands. However, the numerous dams that have been built for various reasons since colonial days effectively extirpated American Shad from the river until recent times. The Fairmount Dam fish ladder, initially installed in the 1970s, underwent major renovation in 2008 and the new fish ladder has the capacity to pass 200,000 to 250,000 shad yearly, according to USFWS, but reaching these numbers would require a significant increase in the overall Delaware River Basin shad population. Between 2009 and 2018, approximately 1,500 shad have been observed passing annually, a significant improvement over the few shad that passed prior to the renovation, but still far below expectations.

Fish passage at the lower four remaining dams on the Schuylkill River could be significantly improved. In addition to depressed basin-wide population, lower than expected passage counts at the Fairmount fish ladder are likely due to issues with the attraction flow, turbulence between pools and at the observation window, and observed predation at the entrance and within the fishway. Passage through the Fairmount Dam fishway will continue to be monitored by the Philadelphia Water Department (PWD). Upstream of Fairmount, many of the dams on the mainstem of the Schuylkill River are either breached or have been removed in the last couple decades. Figure 2 depicts the remaining six dams on the Schuylkill River and whether they have fish passage. The Flat Rock, Norristown (Swede Street), and Black Rock dams all have had fishways added, but technical issues, limited maintenance, and lack of monitoring means that these dams still serve as significant barriers to upstream migration. The New Kernsville Dam, owned by Pennsylvaina Department of Environmental Protection (PA DEP) and located in Hamburg, Pa. at rkm 161, is slated for removal with an estimated completion date in 2022.

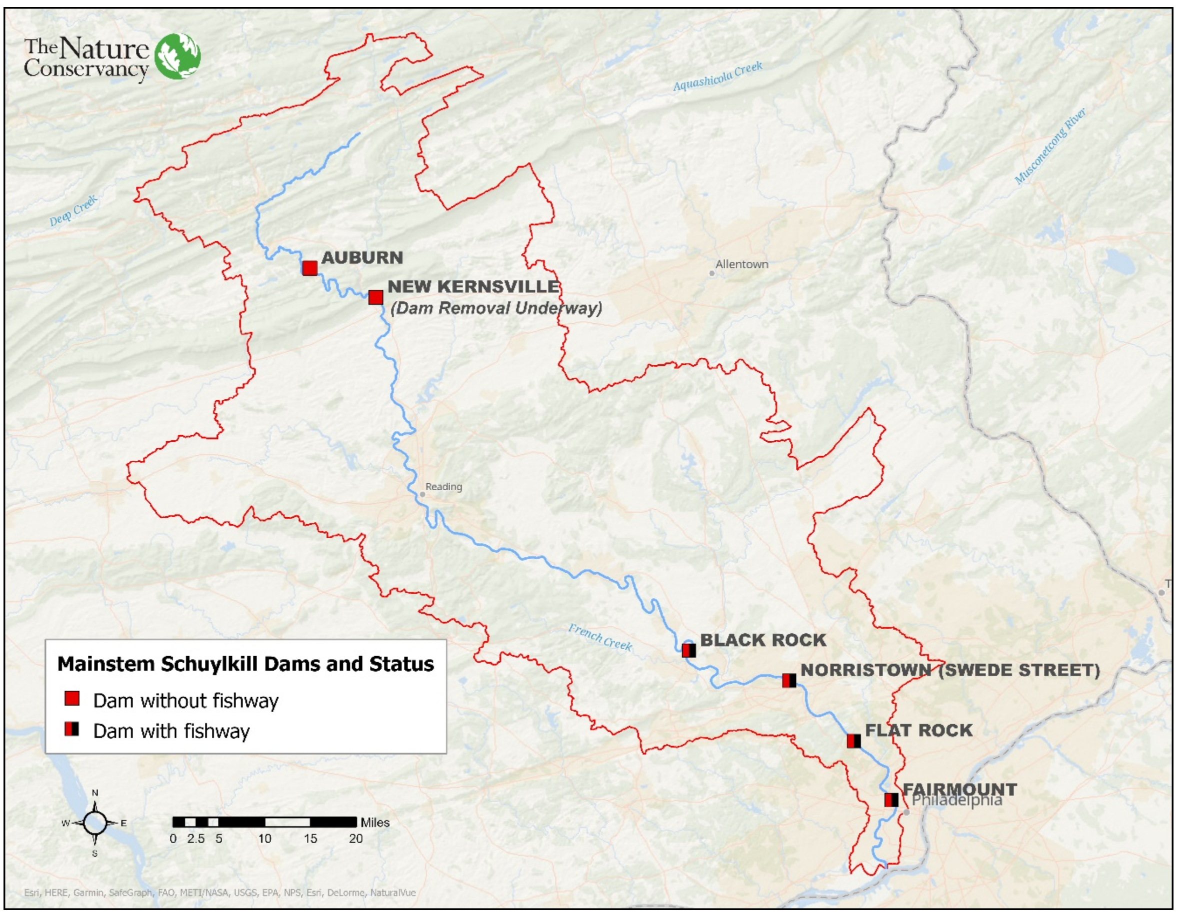

Figure 4: Schuylkill River Dams and Current Status. The map does not show several dams that are either breached or were removed in the last two decades.

Multiple partners are working to restore migratory fish passage within the Brandywine-Christina Basin. In 2014 the Byrnes Mill Dam, also known as White Clay Creek Dam No.1, was removed and planning is underway for the removal of additional dams on White Clay Creek, including the Red Mill and Paper Mill Dams. An active partnership led by Brandywine Shad 2020 is looking to modify or remove each of the 10 remaining dams on the Brandywine that are located along a 5-mile stretch of river from Broom Street in the City of Wilmington to Brandywine State Park and the adjoining portion of New Castle County. In 2017, young-of-year (YOY) American shad were found downstream of the West Street Dam, when 386 YOY were sampled prior to the removal of the dam by the City of Wilmington in 2019. Sampling completed in the summer of 2020 confirmed that shad were spawning in the newly opened section of river upstream of the former West Street Dam and plans are underway for the modification of the next five dams.

Recent restoration efforts in non-tidal New Jersey tributaries have also expanded shad habitat within the Delaware River Basin. Between 2008 and 2016, the Musconetcong River Restoration Partnership removed five dams along the lower portion of the Musconetcong River (rkm 281). In 2017, American Shad were observed at the base of the Warren Mill Dam following the removal of the downstream Hughesville Dam in 2016. The Warren Mill Dam is a 37.5-foot High Hazard Class I Dam vulnerable to a “Sunny Day” breach and its removal will open up an additional three miles of habitat in addition to eliminating a hazard to downstream residents.

Along the Paulins Kill, The Nature Conservancy has been leading efforts to remove a series of dams and reconnect aquatic habitat. In 2018, the Columbia Lake Dam was removed near the mouth of the Paulins Kill and already American Shad have been found 17 kilometers upstream near the base of the Paulina Lake Dam, which is also slated for removal (NJDEP 2019). The Pequest River (rkm 318) is also known to have shad in its lower section and efforts are also underway to remove the two lowermost dams in Belvidere.

Conclusion

The American Shad Habitat Plan for the Delaware River Basin will continue to be updated in future years to reassess restoration efforts and key threats to restoring the shad population within the basin. According to the 2020 ASMFC Stock Assessment for American Shad, the adult mortality for the Delaware River population is currently unsustainable and habitat loss due to barriers is likely restricting positive responses in the coastwide metapopulation abundance (ASMFC 2020). With funding from National Fish and Wildlife Foundation (NFWF), The Nature Conservancy is currently developing a restoration roadmap for American Shad and River Herring in the Delaware River Basin that will lay out a basin-wide strategy for addressing key barriers to migration and improving access to historically significant spawning and rearing habitat. Several partners are already addressing some of these key barriers with recent dam removals or planned removals along major tributaries to the Delaware River, including the Schuylkill River, Brandywine and White Clay creeks, Paulins Kill, and Musconetcong River. Results from the restoration roadmap project will inform future updates to this Plan, with an anticipated final report in 2021.

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Literature Cited and Sources of Spawning Run Information:

[ASMFC] Atlantic States Marine Fisheries Commission. 2020. American Shad Stock Assessment Review Report. Draft for Management Review Board. Prepared by the ASMFC American Shad Stock Assessment Review Panel.

Anonymous. 1961. Big Flat Brook shad. N.J. Outdoors 12(2):28.

Bishop, S.C. 1935. The Shad Fisheries of the Delaware.

Bishop, S. C. 1936. Fisheries investigations in the Delaware and Susquehanna Rivers. N.Y. State Conserv. Dep., 25th Annu. Rep. 1935, Suppl. 10:122-139.

Bovee, K.D., Waddle, T.J., Bartholow, J., and Burris, L., 2007, A decision support framework for water management in the upper Delaware River: U.S. Geological Survey Open-File Report 2007-1172, 122 p. https://www.fwspubs.org/doi/suppl/10.3996/112014-JFWM-084/suppl_file/112014-jfwm-084.s1.pdf

Burns, D.A., J. Klaus, M.R. McHale. 2007. Recent climate trends and implication for water resources in the Catskill Mountain region, New York, USA. Journal of Hydrology 336: 155-170.

Cable, L. E. 1945. The pollution problem in the Delaware River in relation to the restoration of the shad fishery. U.S. Fish and Wildlife Service. Unpub. MS., 9p.

Chittenden, M. E., Jr. 1976. Present and historical spawning grounds and nurseries of American Shad, *Alosa sapidissima*, in the Delaware River. *In* Fishery Bulletin 74: 343-352.

Chittenden, M. E. Jr. 1969. Life history and ecology of the American Shad. Phd thesis, Rutgers University. 458p.

Chittenden, M. E. Jr. 1974. Trends in the Abundance of American Shad, Alosa sapidissima, in the Delaware River Basin. *In* Chesapeake Science 15.2: 96-103.

Compton K. R. 1963. Angler harvest comparisons on the fly-fishing only and open fishing stretches of the Big Flatbrook. D. J. Job Compl. Rep. State N.J. Proj. F-20-R-1, 37 p.

Cummings, Warren D. Sussex County: A History (Newton, New Jersey: Newton Rotary Club, 1964). Transcribed http://archiver.rootsweb.com/th/read/NJSUSSEX/2002-09/1032918263 accessed Feb 28, 2012.

[DNREC] Delaware Department of Natural Resources and Environmental Control. 2005. Delaware Bay and Estuary Assessment Report. 171 pp.

[DNREC] Delaware Department of Natural Resources and Environmental Control. 2020. Anadromous

Species Investigations, Study 2: Shad and Herring Research, Activity 4: Adult alosine abundance, juvenile alosine abundance and American Shad nursery habitat evaluation in the Christina system. Prepared by Park, I.

[DNREC] Delaware Department of Natural Resources and Environmental Control. 2020. Anadromous Species Investigations, Study 2: Shad and Herring Research, Activity 5: Delaware Fish Ladder Operation, Maintenance and Biological Monitoring. Prepared by Boucher, J. and Stangl, M.

[DRBC] Delaware River Basin Commission. 2008. Delaware River State of the Basin Report. Delaware River Basin Commission; West Trenton, NJ. 47pp.

[DRBC] Delaware River Basin Commission. 2010. Delaware River and Bay Integrated List Water Quality Assessment report. Delaware River Basin Commission; West Trenton, NJ; 52 pp.

[DRBC] Delaware River Basin Commission. 2015. Existing Use Evaluation for zones 3, 4, & 5 of the Delaware Estuary based on Spawning and Rearing of Resident and Anadromous Fishes. West Trenton, NJ. https://www.state.nj.us/drbc/library/documents/ExistingUseRpt_zones3-5_sept2015.pdf

[DRBC] Delaware River Basin Commission. 2020. DRBC's Aquatic Life Designated Use Study. Retrieved 4 Dec 2020. https://www.nj.gov/drbc/quality/conventional/designated-use.html

Delaware River Basin Conservation Act of 2015, H.R. 1772, 114th Cong. (2015-2016). . Retrieved: 20 Sep 2020. https://www.congress.gov/bill/114th-congress/house-bill/1772/text

[DRBFWMC] A Review and Recommendations Relating to Fishways within the Delaware Basin, the Delaware River Basin Fish and Wildlife Management Cooperative, 1985, p. 5.

[DRBFWMC] Delaware River Basin Fish and Wildlife Management Cooperative. 2017. Delaware River Sustainable Fishing Plan for American Shad. Submitted to the Atlantic States Marine Fisheries Commission Shad and River Herring Management Board.

[DRBFWMC] Policy for dredging, blasting and overboard disposal update. the Delaware River Basin Fish and Wildlife Management Cooperative, 2012, p. 57.

DePhillip, M. and T. Moberg. 2013. Ecosystem flow recommendations for the Delaware River Basin. The Nature Conservancy. Harrisburg, PA. Retrieved 4 Dec 2020. http://www.njintouch.state.nj.us/drbc/library/documents/TNC_DRBFlowRpt_dec2013.pdf

Eagle Creek Renewable Energy. 2020. Final License Application II: Mongaup River Hydroelectric Projects.

Retrieved: 10 Oct 2020. https://www.eaglecreekre.com/sites/default/files/inline-files/Mongaup_FLA_Vol%20II_E_20200330_Public.pdf

EPA. 2002. Case Study Analysis for the Proposed Section 316(b) Phase II Existing Facilities Rule. Chapter B2. Technical and Economic Descriptions of In Scope Facilities of the Delaware Estuary Transition Zone. Report EPA-821-R-02-002. U.S. Environmental Protection Agency Office of Science and Technology Engineering and Analysis Division Washington, DC.

FFMP. 2017. Agreement for a Flexible Flow Management Program. Retrieved 8 Dec 2020. https://webapps.usgs.gov/odrm/ffmp/flexible-flow-management-program

Fowler, H.W. 1907. Records of Pennsylvania Fishes. *In* The American Naturalist 41.481: 5-21. University of Chicago Press.

Frumhoff, P.C., J.J. McCarthy, J.M. Melillo, S.C. Moser, and D.J. Wuebbles. 2007. Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions. Synthesis report of the Northeast.

Gay, J. 1892. The shad streams of Pennsylvania. *In* Report of the State Commissioners of Fisheries for the years 1889-90-91. Harrisburg, Pa., pp. 151-187.

Gumaer, P.K. 1890. A History of Deerpark in Orange County, N.Y. Minisink Valley Historical Society.

Hardy. Charles. 1999. Fish or Foul: A History of the Delaware River Basin Through the Perspective of the American Shad," *Pennsylvania History* 66:4: 506-534.

Hendricks, M.L., T.R. Bender, and V.A. Mudrak. 1991. Multiple marking of American Shad otoliths With tetracycline antibiotics. North American Journal of Fisheries Management. 11: 212- 219.

Hendricks, M.L., R.L. Hoopes and D.A. Arnold. 2002. Homing of Hatchery reared American Shad to the Lehigh River, a tributary to the Delaware River. North American Journal of Fisheries Management 22:243-248.

Horwitz, R.J., D. Keller, S. Moser and P. Overbeck. 2008. Neversink Shad Study, Final Report. Submitted to The Nature Conservancy, Patrick Center for Environmental Sciences. The Academy of Natural Sciences. 23pp.

Hough, M.P.H. 1936. Early history of Ambler, 1682-1888. Retrieved: 11 May 2020. http://digital.library.upenn.edu/women/hough/ambler/ambler.html

Kauffman, G. 2011. Socioeconomic Value of the Delaware River Basin in Delaware, New Jersey, New York, and Pennsylvania: *The Delaware River Basin, an economic engine for over 400 years.* Final Report. Retrieved: 6 Jan 2012. http://www.state.nj.us/drbc/SocioeconomicValueDRB-UDEL- FinalRpt.pdf

Kreeger, D., J. Adkins, P. Cole, R. Najjar, D. Velinsky, P. Conolly, and J. Kraeuter. 2010. Climate Change and the Delaware Estuary: Three Case Studies in Vulnerability Assessment and Adaptation Planning. Partnership for the Delaware Estuary, PDE Report No. 10-01.

Limburg, K. E., K. A. Hattala, and A. Kahnle. 2003. American Shad in its native range. Pages 125–140 *in* K. E. Limburg and J. R. Waldman, editors. Biodiversity, status, and conservation of the world's shads. American Fisheries Society, Symposium 35, Bethesda, Maryland.

MacGillivray, A. R. 2012. Contaminants of Emerging Concern in the Tidal Delaware River a Pilot Monitoring Survey 2007-2009.Delaware River Basin Commission. West Trenton, NJ.

Mansueti I, R., and H. Kolb. 1953. A historical review of the shad fisheries of North America. *In* Chesapeake Bio. Lab. Pub. 97. 293 p.

Martin, E. H. and C. D. Apse. 2011. Northeast Aquatic Connectivity: An Assessment of Dams on Northeastern Rivers. The Nature Conservancy, Eastern Freshwater Program.

Maurice, K.R., R. W. Blye, and P. L. Harmon. 1987. Increased spawning by American Shad coincident with improved dissolved oxygen in the tidal Delaware River. American Fisheries Society Symposium 1: 79-88.

McDowall.2001. Anadromy and homing: Two life-history traits with adaptive synergies in salmonid fishes? Fish and Fisheries 2: 78–85.

McPhee, J. 2002. The Founding Fish. Farra, Staus and Giroux, New York, NY.

MacGillivray, R.A. 2007. Emerging Contaminants of Concern in the Delaware River Basin Vulnerability Assessment Preliminary Report. A Report to the Delaware River Basin Commission.

Miller, J.P., J.W. Friedersdorff, H.C. Mears and C.W. Billingsley. 1972. Annual progress report, Delaware River Anadromous Fish Project, AFS-2-5; July, 1971-June, 1972. U.S. Fish and Wildlife Service 88p.

Moberg, T., C. Apse, and M. DePhilip. 2010. Flow alteration in the Upper Delaware River Basin: a historical analysis of water supply reservoir management impacts (1954-2009). The Nature Conservancy, Harrisburg, PA.

Moss, S. A. 1970. The responses of young American shad to rapid temperature changes. Transactions of the American Fisheries Society 99: 381-384.

Narvaez, M.C. 2010. Restoration of Shad and Anadromous Fish to the White Clay Creek National Wild and Scenic River: A Feasibility Report. University of Delaware, Water Resources Agency.

[NJDEP] New Jersey Department of Environmental Protection, Division of Fish and Wildlife, Bureau of Freshwater Fisheries. 2005. Locations of Anadromous American Shad and River Herring during their Spawning Period in New Jersey's Freshwaters including known Migratory Impediments and Fish Ladders. Retrieved: 10 Jul 2020. https://www.njfishandwildlife.com/pdf/anadromouswaters.pdf

[NJDEP] New Jersey Department of Environmental Protection, Division of Fish and Wildlife, Bureau of Freshwater Fisheries. 2012. Investigation and Management of Anadromous Fisheries: Inventory and Status of Anadromous Clupeid Spawning Migrations in New Jersey Freshwaters (2002 – 2007). New Jersey Division of Fish and Wildlife. Prepared by Smith, C.

[NJDEP] New Jersey Department of Environmental Protection, Division of Fish and Wildlife, Bureau of Freshwater Fisheries. 2019. American Shad Officially Documented Upstream of Former Columbia Lake Dam. New Jersey Division of Fish and Wildlife. Retrieved 8 Dec 2020. https://www.njfishandwildlife.com/news/2019/paulinskillshad2.htm

[NYT] New York Times. 1889. Shad in the Delaware: Fishways constructing to enable them to pass a dam. Published: September 15, 1889

Pait, A.S. and J. O. Nelson. 2002. Endocrine Disruption in Fish: An Assessment of Recent Research and Results. NOAA Tech. Memo. NOS NCCOS CCMA 149. Silver Spring, MD: NOAA, NOS, Center for Coastal Monitoring and Assessment 55 pp.

[PDE] Partnership for the Delaware Estuary. 2012. Technical Report for the Delaware Estuary and River Basin. Partnership for the Delaware Estuary Report No. 12-01. 255 pp. http://www.delawareestuary.org/science_reports_partnership.asp

[PDE] Partnership for the Delaware Estuary. 2017. Technical Report for the Delaware Estuary and Basin 2017. L. Haaf, S. Demberger, D. Kreeger, and E. Baumbach (eds). PDE Report No. 17-07. 37 https://www.delawareestuary.org/wpcontent/uploads/2018/01/TREB-2017-complete.pdf

[PFBC] Pennsylvania Fish and Boat Commission. 2011. Draft Delaware River Management Plan: A management plan focusing on the large river habitats of the West Branch Delaware River and non-tidal reach of the Delaware River of Pennsylvania. Pennsylvania Fish and Boat Commission, Bureau of Fisheries, Division of Fisheries Management. Harrisburg, PA.

[PFBC] Pennsylvania Fish and Boat Commission. 2012. Next Steps in American Shad Restoration in Pennsylvania. Presentation at the 2012 Watershed Congress at Montgomery County Community College. Retrieved 23 Mar 2020. https://www.delawareriverkeeper.org/sites/default/files/resources/Reports/Next_Steps_in_American_Shad_Restoration_in_Pennsylvania.pdf

[PFBC] Pennsylvania Fish and Boat Commission. 2014. Darby and Neshaminy Creeks 2014 Tidal Largemouth Bass Surveys. Retrieved: 10 Jul 2020. https://pfbc.pa.gov/images/reports/2015bio/6x08_28darbynesh.pdf

[PFBC] Pennsylvania Fish and Boat Commission. 2007. Lehigh River Fisheries Management Plan. Pennsylvania Fish and Boat Commission: Division of Fisheries Management. Prepared by Arnold, D.A. and Pierce, D.J.

Pennsylvania State Commissioners of Fisheries. 1896. Report of the State Commissioners of Fisheries for the Year 1896, PA. Harrisburg, PA.

PSEG Nuclear, LLC. 2018. Biological Monitoring Program for the Delaware River Estuary: 2018 Annual Report.

Ross, R. M., R. M. Bennett, and J. H. Johnson. 1997. Habitat use and feeding ecology of riverine Juvenile American Shad. North American Journal of Fisheries Management 17:964–974.

Savoy T.F., Crecco V.A. Factors affecting the recent decline of Blueback herring and American Shad in the Connecticut River. American Fisheries Society Monograph 2004;9:361-377.

Schutt, A. 2007. Peoples of the River Valleys: The Odyssey of the Delaware Indians. University of Pennsylvania Press. 264 p.

Simpson, R. L., R. E. Good, M. A. Leck, and D. F. Whigham. 1983. The ecology of freshwater tidal wetlands. BioScience 33(4): 255-259.

Slatick, E. and Basham, L. R. 1985. The effect of Denil fishway length on passage of some nonsalmonid fishes. U.S. National Marine Fisheries Service Marine Fisheries Review, 47(1): 83–85.

State of New Jersey v. State of New York and City of New York, 283 U.S. 805 (1954).

Stevenson, C. H. 1899. The shad fisheries of the Atlantic coast of the United States. Pages 101-269 *in* G.M. Bowers. Report of the U.S. Commission of Fish and Fisheries, part 24. U.S. Commission of Fish and Fisheries, Washington, D.C

Stier, D.J. and J.H. Crance. 1985. Habitat suitability index models: American Shad. U.S. Fish Wildlife Service. Biological Report 82 (10.88). Washington, DC

Stoklosa, A.M., Keller, D.H., Marano, R. and Horwitz, R.J. 2018. A Review of Dissolved Oxygen Requirements for Key Sensitive Species in the Delaware Estuary. Academy of Natural Sciences of Drexel University.

Sykes, J.E. and Lehman, B.A. 1957. Past and Present Delaware River Shad Fishery and Considerations for its Future. U.S. Department of the Interior. Washington, DC.

[TNC] The Nature Conservancy. 2017. Ecological flow needs in the Lehigh River: a screening assessment. Prepared for U.S. Army Corps of engineers. Philadelphia District.

U.S. Army Corps of Engineers, Philadelphia District. 2010. Wissahickon Creek Feasibility Study. Presentation on January 14, 2010. Retrieved 4 Apr 2020. https://www.nap.usace.army.mil/Portals/39/docs/Civil/Wissahickon/Wissahickon%20Stakeholder%20Meeting%20Powerpoint%20011410.pdf

U.S. Fisheries Commissioners Annual Reports. 1887-88

U. S. Fish and Wildlife Service. 1999. Restoring anadromous fishes to the Schuylkill River basin. Fact Sheet.

[USGS-NWIS] U.S. Geological Survey, National Water Information System data available on the internet; accessed January 7, 2013, at URL http://waterdata.usgs.gov/nwis (see Station ID #01467200 and # 01477050).

Vajda A .M., Barber, L. B., James L.G, Lopez, E.M., Woodling, J.D. and D. O. Norris. 2008. 1. Reproductive Disruption in Fish Downstream from an Estrogenic Wastewater Effluent Environmental Science & Technology *42*:9: 3407-3414.

Walford, L. A. 1951. Federal Power Commission Project No. 2039, Delaware River. (Memorandum On the restoration of shad in the Delaware River to the Atlantic States Marine Fisheries Commission, from the U. S. Fish and Wildlife Service). Jan. 24: 1-5.

Walter, III, J. F.; Overton, A. S.; Ferry, K. H and M. E Mather. 2003. Atlantic coast feeding habits of striped bass: A synthesis supporting a coast-wide understanding of trophic biology. Fisheries Management and Ecology, 10: 349 - 360.

Weslager C. A. 1989. “The Delaware Indians: A History” Rutgers University Press, New Brunswick, NJ 546 pp.

Zich H. E. 1978. New Jersey Anadromous Fish Inventory: Information on Anadromous Clupeid Spawning in New Jersey. New Jersey Department of Environmental Protection, Bureau of Fisheries. Lebanon, New Jersey

SOUTH CAROLINA HABITAT PLAN FOR AMERICAN SHAD

DNR

South Carolina Department of Natural Resources

April 2021

Introduction:

The purpose of this Habitat Plan is to briefly document existing conditions in rivers with American shad runs, identify potential threats, and propose action to mitigate such threats. American shad (*Alosa sapidissima*) are found in at least 19 rivers of South Carolina (Waccamaw, Great Pee Dee, Little Pee Dee, Lynches, Black, Sampit, Bull Creek, Santee, Cooper, Wateree, Congaree, Broad, Wando, Ashley, Ashepoo, Combahee, Edisto, Coosawhatchie, and Savannah Rivers). Many have historically supported a commercial fishery, a recreational fishery, or both. Currently, commercial fisheries exist in Winyah Bay, Waccamaw, Pee Dee, Black, Santee, Edisto, Combahee, and Savannah Rivers, while the Sampit, Ashepoo, Ashley, and Cooper rivers no longer support commercial fisheries. With the closure of the ocean-intercept fishery beginning in 2005, the Santee River and Winyah Bay complex comprise the largest commercial shad fisheries in South Carolina. Recreational fisheries still exist in the Cooper, Savannah, Edisto, and Combahee Rivers, as well as the Santee River Rediversion Canal. For the purposes of this plan, systems have been identified which, in some cases, include several rivers. Only river systems with active shad runs were included in this plan, these include the Pee Dee River run in the Winyah Bay System (primarily the Waccamaw and Great Pee Dee Rivers), the Santee-Cooper system (Santee and Cooper Rivers with the inclusion of Lakes Moultrie and Marion), and the ACE Basin (Edisto and Combahee Rivers) (Figure 1). A joint plan with Georgia was submitted and approved for the Savannah River.

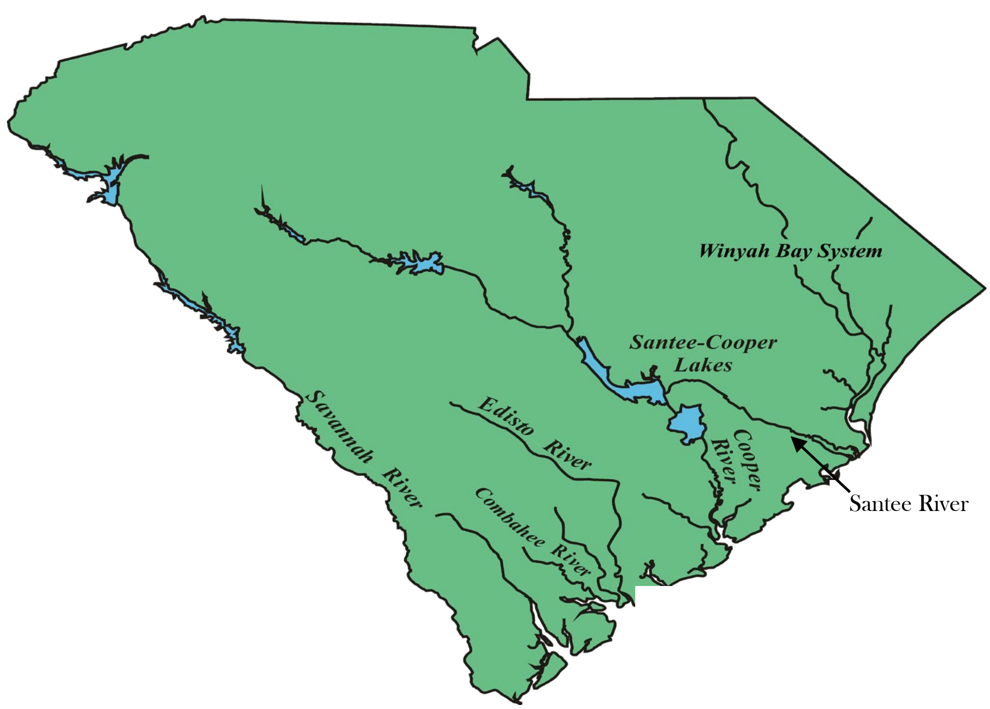

Figure 1. Map of major South Carolina drainage basins and river systems with American shad (*Alosa sapidissima*) fisheries or historical American shad runs.

Pee Dee River System

Habitat Assessment

The Pee Dee River watershed encompasses parts of North Carolina and South Carolina. Beginning in North Carolina in the Appalachian Mountains, tributaries flow out across the piedmont and at the confluence of the Yadkin and Uwharrie Rivers the Great Pee Dee River begins. From there it flows 90 km in North Carolina, and 280 km in South Carolina before emptying into Winyah Bay. The Great Pee Dee River flows unimpeded for its entire length in South Carolina.

Historical Habitat

American shad inhabited all of the Great Pee Dee River (280 km) and had access to all main stem tributaries throughout the 22,258 km^2 watershed within South Carolina (SCDHEC), including Little Pee Dee River (187 km), Lynches River (225 km), Black River (243 km), and Waccamaw River (225 km) in both South Carolina and North Carolina. Stevenson (1899) reported American shad utilized the Pee Dee River throughout its entire length in South Carolina. He also reported American shad were taken 161 km up the Waccamaw River, 210 km up the Black River, and "considerable numbers" were taken 200 km up the Lynches River. Welch (2000), found contradicting reports on the historical presence of American shad in the Little Pee Dee River. A published letter to the U.S. Fish Commissioner from 1887 talked of shad in the Little Pee Dee River (Burns 1887); whereas Stevenson (1899) found no record of American shad caught in large numbers.

Current Useable Habitat

Spawning – American shad have access to all adequate habitats, there are no barriers to migration throughout the South Carolina portion of the watershed. Suitable freshwater riverine channel habitat for spawning occurs ~48 km inland and continues throughout the entire river portion of the Great Pee Dee River in South Carolina and all main stem tributaries.

Rearing - Suitable rearing habitats are similar to the listed waterways for suitable spawning habitat with the addition of 18,158 ha of estuary in the Pee Dee River basin (SCDHEC 2013).

Threats Assessment

a. Barriers to migration inventory and assessment

The Blewett Falls Dam is the furthest downstream dam on the Great Pee Dee River located at km 302. It is a North Carolina facility, however since it affects the spawning run of shad in the Pee Dee River System, it is mentioned briefly in this plan.

Action: Develop a plan for establishing fish passage at barriers in the Pee Dee River System.

Regulatory Agencies/Contacts: USFWS, NMFS, FERC, USACE, South Carolina Department of Natural Resources (SCDNR), North Carolina Wildlife Resources Commission (NCWRC), dam owners and operators, and federal and state legislators.

Goal/Target: Establish fish passage at dams in the Yadkin-Pee Dee River basin, where passage is determined to be feasible.

Progress: As part of the Federal Energy Regulation Commission (FERC) licensing process, hydroelectric facilities in the Yadkin-Pee Dee River Basin (in particular Blewett Falls Dam) are required to implement trap and truck operations by the forth spawning season following the issuance of the license. This phased approach also requires modification of the trap facility and installation of a fish exit flume, allowing direct passage of fish over Blewett Falls.

On April 1, 2015, the Federal Energy Regulatory Commission (FERC; Commission) issued Duke Energy Progress, LLC (Duke Energy) a New License for the Yadkin-Pee Dee Hydroelectric Project (Project, FERC Project No. 2206) Required fish passage and mandated flow requirements associated with the issuance of the license should greatly improve water quality in the system.

Cost: Unknown at this time.

Timeline: 2022-

b. The following is the list provided in 2013 of point source and nonpoint source activities that occur in the Savannah River. Since then, SCDHEC developed an interactive web-based database tool to better assess proposed, ongoing, and/or completed projects. It can be accessed at the following website: https://gis.dhec.sc.gov/watersheds/

Active NPDES Facilities	*Facility Type*	*Permit Number*	*Section Number*	*Section Name*	*Receiving Stream*
INTERNATIONAL PAPER CO./GEORGETOWN	MAJOR INDUSTRIAL	SC0000868	03040207-01	(Sampit River)	SAMPIT RIVER
3V, INC.	MAJOR INDUSTRIAL	SC0036111	03040207-01	(Sampit River)	SAMPIT RIVER
CITY OF GEORGETOWN WWTP	MAJOR DOMESTIC	SC0040029	03040207-01	(Sampit River)	SAMPIT RIVER
CITY OF GEORGETOWN/WTP	MINOR INDUSTRIAL	SCG645013	03040207-01	(Sampit River)	SAMPIT RIVER
ISG GEORGETOWN INC.	MAJOR INDUSTRIAL	SC0001431	03040207-01	(Sampit River)	SAMPIT RIVER
SCPSA/WINYAH STEAM STATION	MAJOR INDUSTRIAL	SC0022471	03040207-01	(Sampit River)	TURKEY CREEK
INTERNATIONAL PAPER CO./SANTEE	MINOR DOMESTIC	SC0042960	03040207-01	(Sampit River)	TURKEY CREEK TRIBUTARY
CWS/WHITES CREEK-LINCOLNSHIRE SD	MINOR DOMESTIC	SC0030732	03040207-01	(Sampit River)	WHITES CREEK
GCSD/DEEP CREEK ELEM SCHOOL	MINOR DOMESTIC	SC0039195	03040207-02	(Great Pee Dee River/Winyah Bay)	BOSER SWAMP
GCSD/PLEASANT HILL ELEM SCHOOL	MINOR DOMESTIC	SC0039101	03040207-02	(Great Pee Dee River/Winyah Bay)	FLAT RUN SWAMP

CAROLINA SAND INC./BRITTONS NECK	MINOR INDUSTRIAL	SCG730043	03040207-02	(Great Pee Dee River/Winyah Bay)	MAPLE SWAMP
JAYCO/CANNONS LAKE MINE	MINOR INDUSTRIAL	SCG730538	03040207-02	(Great Pee Dee River/Winyah Bay)	MAPLE SWAMP
GCW&SD/PLANTERSVILLE EDR	MINOR DOMESTIC	SCG645051	03040207-02	(Great Pee Dee River/Winyah Bay)	CHAPEL CREEK TRIBUTARY
TOWN OF HEMINGWAY/WWTP	MINOR DOMESTIC	SC0039934	03040207-02	(Great Pee Dee River/Winyah Bay)	CLARK CREEK
DELTA MILLS INC./CYPRESS PLANT	MINOR INDUSTRIAL	SCG250151	03040201-12	(Great Pee Dee River)	GREAT PEE DEE RIVER
CAROLINA SAND/GRESHAM PIT	MINOR INDUSTRIAL	SCG730181	03040201-12	(Great Pee Dee River)	GREAT PEE DEE RIVER TRIBUTARY
DELTA MILLS INC./PAMPLICO PLANT	MINOR INDUSTRIAL	SCG250150	03040201-12	(Great Pee Dee River)	MILL BRANCH
TOWN OF PAMPLICO	MINOR DOMESTIC	SC0021351	03040201-12	(Great Pee Dee River)	GREAT PEE DEE RIVER
CITY OF MARION/S. MAIN ST. WWTP	MAJOR DOMESTIC	SC0046230	03040201-10	(Great Pee Dee River)	GREAT PEE DEE RIVER
DUPONT TEIJIN FILMS/FLORENCE PLANT	MAJOR INDUSTRIAL	SC0002917	03040201-10	(Great Pee Dee River)	GREAT PEE DEE RIVER
STONE CONTAINER CORP	MAJOR INDUSTRIAL	SC0000876	03040201-10	(Great Pee Dee River)	GREAT PEE DEE RIVER
MARION CERAMICS, INC./PEE DEE MINE	MINOR INDUSTRIAL	SCG730219	03040201-10	(Great Pee Dee River)	TOBYS CREEK
MOHAWK IND./OAK RIVER PLANT	MINOR INDUSTRIAL	SC0001996	03040201-08	(Great Pee Dee River)	GREAT PEE DEE RIVER
WALKER CONSTR./WALKER BORROW PIT	MINOR INDUSTRIAL	SCG730234	03040201-08	(Great Pee Dee River)	CARTERS BRANCH
DARLINGTON COUNTY/RUSSELL 2 MINE	MINOR INDUSTRIAL	SCG730515	03040201-08	(Great Pee Dee River)	BUCKHOLTZ CREEK TRIBUTARY
HANSON AGGREGATES SE/BROWNSVILLE	MINOR INDUSTRIAL	SCG730468	03040201-08	(Great Pee Dee River)	ROGERS CREEK TRIBUTARY
HANSON AGGREGATES SE/BLENHEIM	MINOR INDUSTRIAL	SCG730039	03040201-08	(Great Pee Dee River)	RIGGINS BRANCH
US CONSTRUCTORS/HANSON PIT	MINOR INDUSTRIAL	CG730435	03040201-08	(Great Pee Dee River)	GREAT PEE DEE RIVER TRIBUTARY
TOWN OF CLIO WWTF	MINOR DOMESTIC	SC0040606	03040201-08	(Great Pee Dee River)	HAGINS PRONG
TOWN OF CHERAW WWTP	MAJOR DOMESTIC	SC0020249	03040201-05	(Great Pee Dee River)	GREAT PEE DEE RIVER
DOMTAR PAPER CO.LLC/MARLBORO MILL	MAJOR INDUSTRIAL	SC0042188	03040201-05	(Great Pee Dee River)	GREAT PEE DEE RIVER
DELTA MILLS INC.	MAJOR INDUSTRIAL	SC0002151	03040201-05	(Great Pee Dee River)	GREAT PEE DEE RIVER
GALEY & LORD, INC./SOCIETY HILL	MAJOR INDUSTRIAL	SC0002704	03040201-05	(Great Pee Dee River)	GREAT PEE DEE RIVER
HANSON AGGREGATES SE/CASH MINE	MINOR INDUSTRIAL	SCG730467	03040201-05	(Great Pee Dee River)	PEE DEE RIVER TRIBUTARY
HANSON AGGREGATES SE/MARLBORO	MINOR INDUSTRIAL	SCG730359	03040201-05	(Great Pee Dee River)	CROOKED CREEK
CITY OF BENNETTSVILLE WWTP	MAJOR DOMESTIC	SC0025178	03040201-05	(Great Pee Dee River)	CROOKED CREEK
US CONSTRUCTION/BERMUDA PIT	MINOR INDUSTRIAL	SCG730472	03040201-05	(Great Pee Dee River)	CROOKED CREEK
MOREE FARMS/PARADISE PIT	MINOR INDUSTRIAL	SCG730558	03040201-05	(Great Pee Dee River)	SPOT MILL CREEK TRIBUTARY
SCHAEFFLER GROUP USA, INC	MINOR INDUSTRIAL	SCG250163	03040201-05	(Great Pee Dee River)	WILSON BRANCH TRIBUTARY
PALMETTO BRICK/IRBY MINE	MINOR INDUSTRIAL	SCG730240	03040201-05	(Great Pee Dee River)	PHILS CREEK
PALMETTO BRICK/ROBERTS MINE	MINOR INDUSTRIAL	SCG730573	03040201-05	(Great Pee Dee River)	PHILS CREEK TRIBUTARY
PALMETTO BRICK/WINBURN MINE	MINOR INDUSTRIAL	SCG730241	03040201-05	(Great Pee Dee River)	CEDAR CREEK
MARLBORO COUNTY/COUNTY PIT	MINOR INDUSTRIAL	SCG730158	03040201-05	(Great Pee Dee River)	BEVERLY CREEK
PALMETTO BRICK/CLINKSCALE MINE	MINOR INDUSTRIAL	SCG730443	03040201-05	(Great Pee Dee River)	BEAVERDAM CREEK TRIBUTARY
PALMETTO BRICK/PEFUES MINE	MINOR INDUSTRIAL	SCG730434	03040201-03	(Great Pee Dee River)	MARKS CREEK
OLD CASTLE STONE/ESKRIDGE MINE	MINOR INDUSTRIAL	SCG730475	03040201-03	(Great Pee Dee River)	GREAT PEE DEE RIVER TRIBUTARY
MARION CERAMICS/PAVER MINE	MINOR INDUSTRIAL	SCG730218	03040201-03	(Great Pee Dee River)	GREAT PEE DEE RIVER TRIBUTARY

Water Quantity					
Water User	***Regulated Cap. (MGD)***	***Pumping Cap. (MGD)***	***Section Number***	***Section Name***	***Stream***
CITY OF GEORGETOWN	5.2	10.5	03040207-02	(Great Pee Dee River/Winyah Bay)	GREAT PEE DEE RIVER
GSW&SA/BULL CREEK REGIONAL WTP	50.87	60.42	03040207-02	(Great Pee Dee River/Winyah Bay)	BULL CREEK
TOWN OF CHERAW	4.5	11.5	03040201-05	(Great Pee Dee River)	GREAT PEE DEE RIVER
CITY OF BENNETTSVILLE	4	6	03040201-05	(Great Pee Dee River)	LAKE WALLACE

All point source, nonpoint source, and water withdrawals that occur in the Pee Dee River System are closely monitored by the South Carolina Department of Health Environmental Control (DHEC). All discharges are held to water quality standards for the state. Therefore, it is highly unlikely these programs impact adult American shad migration and utilization of historic habitat. In addition, all programs are currently undergoing cooling water intake structures rules (40 CFR 122 and 125) analysis to assess the likelihood of impingement or entrainment in efforts to ensure compliance with the proposed EPA 316(b).

c. Toxic and thermal discharge inventory and assessment-none

d. Channelization and dredging

The following is a list of historic dredging programs that occurred in 2013 in the Pee Dee River System. Since then, USACE developed an interactive web-based database tool to better assess proposed, ongoing, and/or completed projects. It can be accessed at the following website: https://permits.ops.usace.army.mil/orm-public

Start_Date	River	DA_Number	Action_Typ	Project_Na	County	Latitude	Longitude
8/20/1993	Pee Dee	SAC-1993-12414	NWP	WATERFORD PLANTATION CANAL	Georgetown	33.428610	-79.194440
7/13/1994	Pee Dee	SAC-1994-10314	LOP	CANAL MAINTENANCE EXCAVATION	Darlington	34.352990	-79.691980
8/9/1994	Pee Dee	SAC-1994-22612	NWP	DREDGING	Georgetown	33.305700	-79.292900
12/2/1994	Pee Dee	SAC-1994-15178	NWP	SAMPIT SHIPARD	Georgetown	33.353890	-79.306670
5/9/1995	Pee Dee	SAC-1995-10620	SP	STATE PIER #32 DREDGING	Georgetown	33.366570	-79.290710
7/17/1996	Pee Dee	SAC-1996-10887	SP	EMERGENCY CANAL DREDGE	Georgetown	33.701700	-79.258600
5/26/1998	Pee Dee	SAC-1998-11458	SP	SANDBAR REMOVAL	Chesterfield	34.707220	-79.876110
11/19/1999	Pee Dee	SAC-1999-11854	SP	GEORGETOWN LANDING MARINA US HWY 17	Georgetown	33.366600	-79.268360
1/3/2003	Pee Dee	SAC-2003-13032	SP	BELLE ISLE MARINA	Georgetown	33.306220	-79.292630
5/13/2008	Pee Dee	SAC-1985-08234-4NJ	NWP	SCWMRD	Horry	33.664130	-79.135730
12/7/2012	Pee Dee	SAC-2000-11969	SP	BELLE ISLE MARINA DREDGING	Georgetown	33.304400	-79.293100

In addition, the shipping channel near Georgetown, SC is 28.8 km long and authorized to 8.2 m. However, funding is rarely available to maintain it. Currently, it is significantly shallower than 8.2 m in some areas.

It is highly unlikely current or past dredging operations are having impacts on adult American shad migration and utilization of historic habitat.

e. The following is a list of land use and mining activities that occurred in 2013 in the Pee Dee River System. Since then, SCDHEC developed an interactive web-based database tool to better assess proposed, ongoing, and/or completed projects. It can be accessed at the following website: https://gis.dhec.sc.gov/watersheds/

Nonpoint Source Management Program				
Landfill Facilities	***Status***	***Permit #***	***Section Number***	***Section Name***
INTERNATIONAL PAPER, INC. LANDFILL	ACTIVE	222435-1601	03040207-01	(Sampit River)
INTERNATIONAL PAPER, INC. LANDFILL	ACTIVE	222654-8001	03040207-01	(Sampit River)
INTERNATIONAL PAPER, INC. LANDFILL	ACTIVE	222654-8002	03040207-01	(Sampit River)
FRASIER COMPOSTING SITE	ACTIVE	222679-3001	03040207-01	(Sampit River)
MCKENZIE WOOD CHIPPING	ACTIVE	222732-3001	03040207-01	(Sampit River)
MILLER WOOD PROCESSING FACILITY	ACTIVE	222763-3001	03040207-01	(Sampit River)
TOWN OF HEMMINWAY COMPOSTING SITE	ACTIVE	451003-3001	03040207-02	(Great Pee Dee River/Winyah Bay)
THOMPSONS LAND CLEARING	ACTIVE	222678-3001	03040207-02	(Great Pee Dee River/Winyah Bay)
SMURFIT STONE CONTAINER CORP.	ACTIVE	213310-1601	03040201-10	(Great Pee Dee River)
FLORENCE COUNTY C&D LANDFILL	ACTIVE	211001-1201	03040201-10	(Great Pee Dee River)
CITY OF BENNETTSVILLE TRANSFER STA.	ACTIVE	351002-6001	03040201-08	(Great Pee Dee River)
MARLBORO COUNTY COMPOSTING FACILITY	ACTIVE	351001-3001	03040201-08	(Great Pee Dee River)
PALMETTO BRICK CO.	ACTIVE	353324-1601	03040201-05	(Great Pee Dee River)
FURR FACILITY C&D LANDFILL	ACTIVE	132670-1201	03040201-05	(Great Pee Dee River)
MCDUFFIE & SON COMPOSTING	ACTIVE	352691-3001	03040201-05	(Great Pee Dee River)
WEYERHAEUSER COMPANY	ACTIVE	353301-1601	03040201-05	(Great Pee Dee River)
WEYERHAEUSER COMPANY	ACTIVE	353301-8001	03040201-05	(Great Pee Dee River)
CHESTERFIELD COUNTY LANDFILL	ACTIVE	131001-1601	03040201-05	(Great Pee Dee River)

Mining Activities	***Mineral***	***Permit #***	***Section Number***	***Section Name***
SAMPIT MINE	SAND	1639-43	03040207-01	(Sampit River)
HARMONY TOWNSHIP LAKES 1&2	SAND	1655-43	03040207-01	(Sampit River)
GRESHAM MINE NECK SAND MINE #2	SAND	0899-67	03040207-02	(Great Pee Dee River/Winyah Bay)
BACCHUS LAKE MINE	SAND	1682-67	03040207-02	(Great Pee Dee River/Winyah Bay)
CANNONS LAKE MINE	SAND	1552-67	03040207-02	(Great Pee Dee River/Winyah Bay)
WHITE HALL SAND MINE	SAND	1675-67	03040207-02	(Great Pee Dee River/Winyah Bay)
RICHARDSON MINE	SAND/GRAVEL	1765-67	03040207-02	(Great Pee Dee River/Winyah Bay)
JOHNSON ROAD MINE	SAND	1704-67	03040207-02	(Great Pee Dee River/Winyah Bay)
CHARLIE RICHARDSONS LAKE MINE	SAND	1776-67	03040207-02	(Great Pee Dee River/Winyah Bay)
PEE DEE CERAMICS MINE	CLAY	0050-67	03040201-10	(Great Pee Dee River)
BAKER BROTHERS OF GRESHAM INC	SAND; SAND/CLAY	0959-31	03040201-08	(Great Pee Dee River)
RUSSELL MINE #2	SAND/CLAY	0967-31	03040201-08	(Great Pee Dee River)
WALKER BORROW PIT	SAND	1195-69	03040201-08	(Great Pee Dee River)
BROWNSVILLE PLANT	SAND/GRAVEL	0090-69	03040201-08	(Great Pee Dee River)
CLINKSCALE	SAND	1528-69	03040201-05	(Great Pee Dee River)
MARLBORO PIT	CLAY	0171-69	03040201-05	(Great Pee Dee River)
ROBERTS MINE	SAND	1559-69	03040201-05	(Great Pee Dee River)

CASH PLANT	SAND/GRAVEL	0092-25	03040201-05	(Great Pee Dee River)
PEE DEE MINE	SAND/GRAVEL	0466-25	03040201-05	(Great Pee Dee River)
MARLBORO COUNTY PIT	SAND/CLAY	0280-69	03040201-05	(Great Pee Dee River)
BURNT FACTORY MINE	SAND/CLAY	1716-69	03040201-05	(Great Pee Dee River)
MARLBORO PLANT	SAND/GRAVEL	0095-69	03040201-05	(Great Pee Dee River)
MARLBORO FIELD PLANT	SAND/GRAVEL	0096-69	03040201-05	(Great Pee Dee River)
WINBURN	KAOLIN	0997-25	03040201-05	(Great Pee Dee River)
PEGUES MINE	SHALE	1485-69	03040201-03	(Great Pee Dee River)
MARLBORO COUNTY MINE	SAND	0726-69	03040201-03	(Great Pee Dee River)
MARION CERAMICS INC. - PAVER MINE	SHALE	0550-69	03040201-03	(Great Pee Dee River)

All land use and mining activities that occur in the Pee Dee River System are closely monitored by the South Carolina Department of Health Environmental Control (DHEC). Therefore, it is highly unlikely these programs impact adult American shad migration and utilization of historic habitat.

f. Atmospheric deposition

Atmospheric deposition is measured as a cooperative effort between many different groups, including federal, state, tribal and local governmental agencies, educational institutions, private companies, and non-governmental agencies as part of the National Atmospheric Deposition Program (NADP). This organization uses many networks (NTN, AIRMoN, MDN, AMNet, and AMNoN) to monitor methyl mercury, ammonia, etc. Detailed information concerning atmospheric deposition in SC can be found at the following website: http://nadp.sws.uiuc.edu/data/annualmaps.aspx

It does not appear that current levels of atmospheric deposition are impacting American shad migrations or utilization of historic habitat.

g. Climate change assessment

A changing climate will present water-related challenges for American shad in several areas including: water quality, water quantity and changes in sea level. Current climate models predict continued warming across the southeast, with the greatest temperature increases projected in summer. Average annual temperatures are projected to rise 4.5°F by the 2080s under a lower emissions scenario and 9°F under a higher emissions scenario with a 10.5°F increase in summer. The frequency, duration and intensity of droughts are likely to continue to increase with higher average temperatures and a higher rate of evapotranspiration. Drought conditions could potentially impact American shad recruitment and long duration drought could negatively impact multiple year classes. Sea level rise is of concern because of the expected change in location of the saltwater/freshwater interface. As sea level rises, saltwater will move further up the river systems of the state thus reducing the amount freshwater spawning habitat available. The amount and distribution of aquatic vegetation also will change in response to increases in salinity, limiting cover and food sources for aquatic organisms. A changing climate will impact the water resources of South Carolina and will present challenges for American shad management.

Action: Develop a climate change plan.

Regulatory Agencies/Contacts: SC Department of Natural Resources (SCDNR)

Goal/Target: Establish recommendations to address climate change.

Progress: A "draft" plan has been developed and is still under review (Appendix 1)

Cost: Unknown at this time.

Timeline: Unknown

h. Competition and predation by invasive and managed species assessment

Aquatic invasive species occur throughout South Carolina's coastal rivers, and non-native ictalurids are some of the most ubiquitous invasive species. Flathead catfish (*Pylodictis olivaris*) and blue catfish (*Ictalurus furcatus*) were introduced into South Carolina in 1964 and are now found in all of South Carolina's coastal rivers. A significant portion of blue catfish and especially flathead catfish diet is comprised of fish, and due to their large adult size (>60 lbs) they have the potential to consume both adult and juvenile American shad. Ictalurid population information is currently unavailable for South Carolina's coastal rivers; however current studies are occurring in South Carolina and other neighboring states to assess the potential impacts of non-native catfish on American shad.

Action: Develop an invasive species plan.

Regulatory Agencies/Contacts: SC Department of Natural Resources (SCDNR)

Goal/Target: Establish recommendations to address invasive species.

Progress: SCDNR programs are currently monitoring catch rates of invasive catfish as part of non-targeting sampling and any flat head catfish captured during these activities are being removed from the system. In addition, current eradication programs, such as those on the Satilla River, GA, are being reviewed by SCDNR staff to determine if such programs are feasible for SC Rivers.

Cost: Unknown at this time.

Timeline: Unknown

Santee-Cooper System

Habitat Assessment

Watersheds in the Santee River basin begin in the foothills of the Blue Ridge Mountains, flow across the piedmont and coastal plain before emptying in the Atlantic Ocean. Santee River basin is the second largest watershed on the Atlantic coast of the United States, and through the works of man in the 1940's the Santee River was directly connected to the Cooper River. The connection was made by building Santee (Wilson) Dam on the Santee River at ~km 145 creating Lake Marion, then Lake Moultrie was constructed by diking and the two lakes were connected via a canal. Pinopolis Dam was constructed on Lake Moultrie and a ~7 km tailrace canal was dug to deliver the majority of the Santee River flow into Cooper River. Prior to the diversion of the Santee River, the Cooper River was a coastal plain, tidally influenced tributary to Charleston Harbor. In 1985, a 18.5 km rediversion canal and St. Stephens Dam were completed that rerouted a majority of the Santee River flow back to the historical Santee River channel at ~rkm 85.

Historical Habitat

Prior to dam construction, American shad inhabited many major rivers with suitable spawning and rearing habitat throughout a 27,454 km^2 watershed in South Carolina and a 13,726 km^2 watershed in North Carolina, these included the Santee River (230 km), and its major tributaries the Wateree River (120 km), Congaree River (76 km), Broad River (241 km), and the Catawba River (350 km) located in South Carolina and North Carolina. Although the complete distribution of American shad is unknown there were also historical records from smaller tributaries of the Broad River; such as Saluda River, Enoree River, Tyger River, and Pacolet River (Welch, 2000). The Cooper River also provided 67 km of suitable habitat.

Current Useable Habitat

Spawning – American shad begin spawning in tidal freshwater near rkm 48, and have about 105 km of suitable riverine channel habitat for spawning in the Santee River below the Santee-Cooper Dams and an additional 40km in the Cooper River (McCord 2003). Two of the three dams of the Santee-Cooper reservoir project provide American shad passage. A boat lock at Pinopolis Dam is operated for anadromous fish passage on the Cooper River, and a fish lift operates for anadromous fish passage at St. Stephens Dam on the rediversion canal. These passage facilities provide American shad access to areas of suitable spawning habitat such as Lake Marion (44,515 ha), Upper Santee River (above Lake Marion) (9.5 km), Wateree River to the base of Wateree Dam (121 km), Congaree River (76 km), and Broad River to the Columbia Diversion Dam (4 km). An additional fishway at Columbia Diversion Dam provides passage for American shad in the Broad River to the base of Parr Dam (39 km). Adult American shad are annually encountered in all currently available habitats.

Rearing-Suitable rearing habitats are similar to the listed waterways for suitable spawning habitat with the addition of Lake Moultrie (24,281 ha), and the estuaries of the Santee River basin (7,420 ha) and Charleston Harbor (18,518 ha) (SCDHEC 2013).

Threats Assessment

a. Barriers to migration inventory and assessment

The following are a list of dams on the Santee Cooper River System:

Name	Pupose	Owner	Height (ft.)	Width (ft.)	Length (ft.)	Impoundment size (ha)	Water storage capacity (acre/ ft.)	Location	River Kilometer	Fish Passage	Method
Jefferies Dam	Hydro	Santee-Cooper	~85	~60	11,500	38,400	1,129,480	33°14'40.78"N/79°59'28.95"W	77	Yes	Lock
Santee Dam	Hydro	Santee-Cooper	48	~30	40,940	24,000	1,180,800	33°27'13.59"N/ 80° 9'50.30"W	140	No	
St. Stephen Dam	Hydro	Santee-Cooper	128	~156	965	38,400	1,129,480	33°25'36.19"N/79°55'51.57"W	84	Yes	Fish Lock

Action: Develop a plan for establishing fish passage at barriers in the Santee Cooper River System.

Regulatory Agencies/Contacts: USFWS, NMFS, FERC, USACE, South Carolina Department of Natural Resources (SCDNR), dam owners and operators, and federal and state legislators.

Goal/Target: Establish fish passage at dams in the Santee Cooper River River basin, where passage is determined to be feasible.

Progress: As part of the Federal Energy Regulation Commission (FERC) licensing process, hydroelectric facilities in the Santee Cooper River Basin (in particular Santee Dam) are required provide upstream and downstream passage for anadromous fishes following the issuance of the license. This will require construction of a fishway at the Santee Dam and modifications at the Jefferies Dam (Pinopolis Lock). In addition, mandated flow requirements associated with the issuance of the license should greatly improve water quality in the system.

A Biological Opinion for Atlantic and shortnose sturgeon from NMFS was issued 01/22/2020. However, to date, FERC has yet to issue a license for the Santee Cooper Project (Project, FERC Project No. 199).

Cost: Unknown at this time.

Timeline: unknown

b. The following is a list of point source and nonpoint sources that occurred in 2013 in the Santee River. Since then, SCDHEC developed an interactive web-based database tool to better assess proposed, ongoing, and/or completed projects. It can be accessed at the following website: https://gis.dhec.sc.gov/watersheds/

Active NPDES Facilities	*Facility Type*	*Permit Number*	*Section Number*	*Section Name*	*Receiving Stream*
GCW&SD NORTH SANTEE WWTP	MINOR DOMESTIC	SC0042439	03050112-060	(North Santee River/South Santee River)	NORTH SANTEE RIVER
SCPSA/WINYAH STEAM	MAJOR INDUSTRIAL	SC0022471	03050112-060	(North Santee River/South Santee River)	NORTH SANTEE RIVER
TOWN OF ST STEPHEN	MINOR DOMESTIC	SC0025259	03050112-030	(Santee River)	SANTEE RIVER
CHARGEURS WOOL (USA), INC.	MAJOR INDUSTRIAL	SC0000990	03050112-030	(Santee River)	SANTEE RIVER
MARTIN MARIETTA/GEORGETOWN II (SOUTHERN AGGR.)	MINOR INDUSTRIAL	SCG730059	03050112-030	(Santee River)	DUTART CREEK
US ARMY/ST. STEPHEN POWER PLANT	MINOR INDUSTRIAL	SC0047937	03050112-020	(Rediversion Canal)	REDIVERSION CANAL
GA PACIFIC RESINS/RUSSELVILLE/CHEM	MINOR INDUSTRIAL	SCG250181	03050112-020	(Rediversion Canal)	REDIVERSION CANAL
GA PACIFIC CORP./RUSSELVILLE/PARTICLE	MINOR INDUSTRIAL	SCG250179	03050112-020	(Rediversion Canal)	REDIVERSION CANAL
ALBANY INTNL/PRESS FABRIC	MINOR INDUSTRIAL	SC0002569	03050112-020	(Rediversion Canal)	CURRIBOO BRANCH
WILLIAMSBURG CO. W&SA/SANTEE RIVER WWTP	MINOR DOMESTIC	SC0048097	03050112-010	(Santee River)	SANTEE RIVER
PINEWOOD SITE-HILLS/LABRUCE MINE	MINOR INDUSTRIAL	SCG730026	03050111-010	(Santee River)	LAKE MARION
PINEWOOD CUSTODIAL TRUST	MINOR INDUSTRIAL	SC0042170	03050111-010	(Santee River)	LAKE MARION
MARTIN MARIETTA/BERKELEY QUARRY	MINOR INDUSTRIAL	SCG730058	03050111-010	(Santee River)	LAKE MARION TRIBUTARY
TOWN OF PINEWOOD WWTP	MINOR DOMESTIC	SC0046868	03050111-010	(Santee River)	BALLARD CREEK

Nonpoint Source Management Program				
Landfill Facilities	*Status*	*Permit #*	*Section Number*	*Section Name*
GA PACIFIC CORP. CHEM.	ACTIVE	083304-1601 (IWP-078, CWP-026)	03050112-020	(Rediversion Canal)
DUKE POWER CO.	ACTIVE	463303-1601 (IWP-192, IWP-128)	03050111-010	(Santee River)
JF CLECKLEY & CO./PLT #4		IWP-025, IWP-023	03050111-010	(Santee River)
JF CLECKLEY & CO./PLT #6		IWP-060	03050111-010	(Santee River)
LAIDLAW ENVIR. SERVICES	ACTIVE	IWP-145	03050111-010	(Santee River)

The following is a list of point source and nonpoint sources that occurred in 2013 in the Cooper River. Since then, SCDHEC developed an interactive web-based database tool to better assess proposed, ongoing, and/or completed projects. It can be accessed at the following website: https://gis.dhec.sc.gov/watersheds/

Active NPDES Facilities	*Facility Type*	*Permit Number*	*Section Number*	*Section Name*	*Receiving Stream*
MEAD WESTVACO SC	MAJOR INDUSTRIAL	SC0001759	03050201-050	(Cooper River)	COOPER RIVER
AMERADA HESS/VIRGINIA AVE. N.	MINOR INDUSTRIAL	SC0002852	03050201-050	(Cooper River)	COOPER RIVER
AMERADA HESS/VIRGINIA AVE. S.	MINOR INDUSTRIAL	SC0002861	03050201-050	(Cooper River)	COOPER RIVER
ALLIED TERMINALS/CHARLESTON	MINOR INDUSTRIAL	SC0001350	03050201-050	(Cooper River)	COOPER RIVER
SOPUS PRODUCTS/CHAS	MINOR INDUSTRIAL	SC0003026	03050201-050	(Cooper River)	COOPER RIVER
SUN CHEMICAL CORP.	MAJOR DOMESTIC	SC0003441	03050201-050	(Cooper River)	COOPER RIVER
US NAVY/WEAPONS STATION	MINOR INDUSTRIAL	SC0043206	03050201-050	(Cooper River)	COOPER RIVER
NCSD/FELIX DAVIS WWTP	MAJOR DOMESTIC	SC0024783	03050201-050	(Cooper River)	COOPER RIVER
OAK AMERICAS LLC/COOPER RIVER PLT.	MAJOR INDUSTRIAL	SC0026506	03050201-050	(Cooper River)	COOPER RIVER
BP AMOCO CHEMICALS/COOPER RIVER	MAJOR INDUSTRIAL	SC0028584	03050201-050	(Cooper River)	COOPER RIVER
BCW&SA/LOWER BERKELEY WWTP	MAJOR DOMESTIC	SC0046060	03050201-050	(Cooper River)	COOPER RIVER
NUCOR STEEL/BERKELEY PLT	MAJOR INDUSTRIAL	SC0047392	03050201-050	(Cooper River)	COOPER RIVER

MT PLEASANT WATER PLANT #2	MINOR DOMESTIC	SC0043273	03050201-050	(Cooper River)	COOPER RIVER
EVENING POST PUBLISHING CO.	MINOR INDUSTRIAL	SCG250040	03050201-050	(Cooper River)	COOPER RIVER TRIBUTARY
CHARLESTON CPW/DANIEL ISLAND	MINOR DOMESTIC	SC0047074	03050201-050	(Cooper River)	TIDAL CREEK TO COOPER RIVER
SCE&G/WILLIAMS STATION	MAJOR INDUSTRIAL	SC0003883	03050201-050	(Cooper River)	TIDAL CREEK TO COOPER RIVER
DEFENSE FUEL SUPPORT PT/CHAS	MINOR INDUSTRIAL	SCG340022	03050201-050	(Cooper River)	FILBIN CREEK
MEAD WESTVACO CORP/CHAS	MAJOR INDUSTRIAL	SC0001759	03050201-050	(Cooper River)	FILBIN CREEK
KINDER MORGAN BULK TERM./N. CHAS	MINOR INDUSTRIAL	SCG340015	03050201-050	(Cooper River)	FILBIN CREEK
KINDER MORGAN BULK TERM./SHIPYARD RIV. TERM	MINOR INDUSTRIAL	SC0048046	03050201-050	(Cooper River)	SHIPYARD CREEK
MONTENAY CHARLESTON/RESOURCE RECOVERY	MINOR INDUSTRIAL	SC0041173	03050201-050	(Cooper River)	SHIPYARD CREEK
TOWN OF MONCKS CORNER WWTP	MAJOR DOMESTIC	SC0021598	03050201-030	(West Branch Cooper River)	WEST BRANCH COOPER RIVER
BCW&SA/CENTRAL BERKELEY WWTP	MINOR DOMESTIC	SC0039764	03050201-030	(West Branch Cooper River)	WEST BRANCH COOPER RIVER
SCE&G/WILLIAMS ASH DISP	MINOR INDUSTRIAL	SC0046175	03050201-030	(West Branch Cooper River)	WAPPOOLA SWAMP
SCE&G/WILLIAMS LANDFILL	MINOR INDUSTRIAL	SC0039535	03050201-030	(West Branch Cooper River)	MOLLY BRANCH
OAKLEY MAINTENANCE FACILITY MINOR DOMESTIC	MINOR DOMESTIC	SC0026867	03050201-030	(West Branch Cooper River)	MOLLY BRANCH TRIBUTARY
D&A PARTNERSHIP/DANGERFIELD MINE	MINOR INDUSTRIAL	SCG730125	03050201-030	(West Branch Cooper River)	MOLLY BRANCH
SCPSA/CROSS GENERATING STATION	MAJOR INDUSTRIAL	SC0037401	03050201-010	(Lake Moultrie)	DIVERSION CANAL
US NAVY/SHORT STAY REC. FAC.	MINOR INDUSTRIAL	SC0024708	03050201-010	(Lake Moultrie)	LAKE MOULTRIE
BERKELEY COUNTY/CROSS HIGH SCHOOL	MINOR DOMESTIC	SC0027103	03050201-010	(Lake Moultrie)	LAKE MOULTRIE
SCPSA/JEFFERIES GENERATING STATION	MAJOR INDUSTRIAL	SC0001091	03050201-010	(Lake Moultrie)	TAIL RACE CANAL
C.R. BARD, INC.	MAJOR INDUSTRIAL	SC0035190	03050201-010	(Lake Moultrie)	TAIL RACE CANAL
SCPSA/MONCKS CORNER WTP	MINOR DOMESTIC	SCG641011	03050201-010	(Lake Moultrie)	TAIL RACE CANAL
BERKELEY COUNTY/CROSS ELEM SCHOOL	MINOR DOMESTIC	SC0034479	03050201-010	(Lake Moultrie)	DUCK POND CREEK

Nonpoint Source Management Program				
Landfill Facilities	***Status***	***Permit #***	***Section Number***	***Section Name***
WESTVACO LANDFILL	ACTIVE	IWP-177, IWP-090, IWP-150	03050201-050	(Cooper River)
SCE&G/WILLIAMS STATION	ACTIVE	083320-1601 (IWP-191)	03050201-030	(West Branch Cooper River)
SCE&G/GENCO/WILLIAMS STATION	ACTIVE	083309-1601	03050201-030	(West Branch Cooper River)
BERKELEY COUNTY LANDFILL	ACTIVE	081001-1101	03050201-030	(West Branch Cooper River)
SCPSA/CROSS GENERATING STATION	ACTIVE	085801-1601	03050201-010	(Lake Moultrie)
C&D LANDFILL	--------	083322-1201	03050201-010	(Lake Moultrie)

All point source and nonpoint sources that occur in the Santee Cooper River System are closely monitored by the South Carolina Department of Health Environmental Control (DHEC). All discharges are held to water quality standards for the state. Therefore, it is highly unlikely these programs impact adult American shad migration and utilization of historic habitat. In addition, all programs are currently undergoing Cooling Water Intake Structures Rules (40 CFR 122 and 125) analysis to assess the likelihood of impingement or entrainment in efforts to ensure compliance with the proposed EPA 316(b).

c. Toxic and thermal discharge inventory and assessment-none

d. Channelization and dredging

The following is a list of historic dredging programs that occurred in the Cooper River System. Since then, USACE developed an interactive web-based database tool to better assess proposed, ongoing, and/or completed projects. It can be accessed at the following website: https://permits.ops.usace.army.mil/orm-public

Start_Date	River	DA_Number	Action_Typ	Project_Na	County	Latitude	Longitude
9/9/1993	Cooper	SAC-1993-10092	SP	MAINTENANCE EXCAVATION	Berkeley	33.210830	-79.976110
9/2/1994	Cooper	SAC-1994-10386	SP	TAIL RACE CANAL DUCT SYSTEM	Berkeley	33.212300	-79.974540
4/10/1995	Cooper	SAC-1995-10597	SP	MARITIME CENTER	Charleston	32.787740	-79.926830
7/20/1995	Cooper	SAC-1995-10659	SP	MAINTENANCE DREDGING	Charleston	32.882200	-79.964600
11/24/1995	Cooper	SAC-1995-10730	SP	REISSUE 854D324 DREDGING	Charleston	32.883330	-79.966670
8/29/1995	Cooper	SAC-1995-12639	NWP	YACHT BASIN DREDGING	Charleston	32.772790	-79.926430
2/8/1996	Cooper	SAC-1996-10773	SP	MAINTENANCE DREDGING NAVY BASE	Charleston	32.883330	-79.966670
8/20/1996	Cooper	SAC-1996-10943	SP	DREDGING AT PIER P	Charleston	32.851390	-79.945830
9/22/1997	Cooper	SAC-1997-11257	SP	PIERS TANGO & SIERRA	Charleston	32.849720	-79.938330
8/7/1997	Cooper	SAC-1997-13631	NWP	METAL TRADES INC PIER H	Charleston	32.859530	-79.959140
6/23/1997	Cooper	SAC-1997-22569	NWP	SILTING NAVIGATION PROBLEMS	Berkeley	33.181100	-79.976900
6/18/1997	Cooper	SAC-1997-22633	NWP	DREDGE CANAL	Berkeley	33.180500	-79.975000
3/19/1998	Cooper	SAC-1998-11402	SP	BETWEEN PIER TANGO AND PIER SIERRA	Charleston	32.849720	-79.938330
1/29/1999	Cooper	SAC-1999-11623	SP	STATE PIER 8 MAINTENANCE DREDGING	Charleston	32.798620	-79.930090
4/30/1999	Cooper	SAC-1999-11708	SP	ATF MAINTENANCE DREDGING	Charleston	32.829440	-79.937780
8/6/1999	Cooper	SAC-1999-11777	SP	MAINTENANCE DREDGING LOP	Charleston	32.829440	-79.937780
7/5/2000	Cooper	SAC-2000-11971	SP	MAINTENANCE DREDGING STATE PIER 15	Charleston	32.902700	-79.959400
7/5/2000	Cooper	SAC-2000-11972	SP	UNION PIER TERMINAL STATE PIER 2	Charleston	32.781390	-79.923610
4/11/2001	Cooper	SAC-2001-12267	SP	CHARLESTON NAVAL COMPLEX DREDGING	Charleston	32.863700	-79.963200
4/11/2001	Cooper	SAC-2001-12268	SP	MAINTENANCE DREDGING PIERS Z M & N	Charleston	32.852200	-79.947400
4/11/2001	Cooper	SAC-2001-12269	SP	MAINTENANCE DREDING PIER P	Charleston	32.883330	-79.966670
10/2/2001	Cooper	SAC-2001-12429	SP	BERTH MAINTENANCE DREDGING	Charleston	32.883010	-79.967970
7/8/2002	Cooper	SAC-2002-12823	SP	COOPER RIVER MARINA EXPANSION	Charleston	32.831750	-79.935020
1/2/2003	Cooper	SAC-2003-13026	SP	UNION PIER TERMINAL STATE PIER 2	Charleston	32.783900	-79.924400
3/12/2003	Cooper	SAC-2003-13099	SP	COLUMBUS STREET TERMINAL	Charleston	32.793790	-79.926260
4/22/2005	Cooper	SAC-2005-15947	NWP	BIGGINS LANDING - MINOR DREDGING	Berkeley	33.212190	-79.973770
11/16/2006	Cooper	SAC-2006-03557	SP	BERTH MAINTENANCE DREDGING	Charleston	32.881390	-79.967500
12/14/2006	Cooper	SAC-2006-03772	SP	BIGGINS LANDING DREDGING (SANTEE COOPER)	Berkeley	33.212950	-79.973900

The following is a list of historic dredging programs that occurred in the Santee Cooper Lakes System. Since then, USACE developed an interactive web-based database tool to better assess proposed, ongoing, and/or completed projects. It can be accessed at the following website: https://permits.ops.usace.army.mil/orm-public

Start_Date	River	DA_Number	Action_Typ	Project_Na	County	Latitude	Longitude
4/19/1993	Santee Cooper Lakes	SAC-1993-17035	NWP	SANTEE LAKES	Calhoun	33.541020	-80.509260
11/5/1993	Santee Cooper Lakes	SAC-1993-18242	NWP	MAINTENANCE DREDGING CROSS S/D	Berkeley	33.328000	-80.146000
11/1/1993	Santee Cooper Lakes	SAC-1993-18243	NWP	MAINTENANCE EXCAVATION	Orangeburg	33.500000	-80.452780
1/11/1994	Santee Cooper Lakes	SAC-1994-10173	SP	BOAT SLIP EXCAVATION	Clarendon	33.481940	-80.374440
4/21/1994	Santee Cooper Lakes	SAC-1994-12510	NWP	STUMP HOLE LANDIANG DREDGE	Clarendon	33.570000	-80.503330
11/15/1994	Santee Cooper Lakes	SAC-1994-18248	NWP	MAINTENANCE DREDGING	Berkeley	33.230870	-80.018930
7/31/1996	Santee Cooper Lakes	SAC-1996-10902	SP	LAND O PINES S/D CANAL DREDGE	Berkeley	33.219200	-80.047100
8/5/1996	Santee Cooper Lakes	SAC-1996-10917	SP	FRANCIS MARION S/D DREDGING	Clarendon	33.481900	-80.380600
1/9/1997	Santee Cooper Lakes	SAC-1997-11060	SP	POLLYS LANDING MARINA	Clarendon	33.509700	-80.423600

11/7/1997	Santee Cooper Lakes	SAC-1997-12902	NWP	JACK'S HOLE CANAL MAINTENANCE	Berkeley	33.333500	-79.994640
8/30/1999	Santee Cooper Lakes	SAC-1999-11801	SP	COVE 1 MAINTENANCE EXCAVATION	Clarendon	33.496180	-80.412270
3/10/1999	Santee Cooper Lakes	SAC-1999-15973	NWP	EXCAVATION	Clarendon	33.482450	-80.386920
2/17/1999	Santee Cooper Lakes	SAC-1999-22910	NWP	EXCAVATION NEAR SPIERS LANDING	Berkeley	33.384900	-80.181700
1/10/2000	Santee Cooper Lakes	SAC-2000-11876	SP	CANAL EXCAVATION JACKS HOLE	Berkeley	33.333540	-79.994640
10/19/2000	Santee Cooper Lakes	SAC-2000-15941	NWP	MAINTENACE EXCAVATION	Berkeley	33.341700	-80.123000
10/1/2001	Santee Cooper Lakes	SAC-2001-11358	NWP	127 Waterfront Drive CHANNEL EXCAVATION	Orangeburg	33.416230	-80.323940
4/17/2001	Santee Cooper Lakes	SAC-2001-12271	SP	DIVERSION CANAL S/D MAINTENANCE EXCAVAT	Berkeley	33.387070	-80.144170
6/6/2002	Santee Cooper Lakes	SAC-2002-15847	NWP	DREDGING FILL	Berkeley	33.315700	-79.999000
11/3/2003	Santee Cooper Lakes	SAC-2003-14167	NWP	CANAL UPGRADE	Berkeley	33.384300	-80.139200
1/10/2007	Santee Cooper Lakes	SAC-2007-00073	SP	JACK'S HOLE DREDGING (SANTEE COOPER)	Berkeley	33.366800	-79.996760
11/26/2007	Santee Cooper Lakes	SAC-2007-02647	SP	MAINTENANCE SAND REMOVAL AT COVE ENTRANCE	Orangeburg	33.487700	-80.447900
1/2/2008	Santee Cooper Lakes	SAC-2008-00088	SP	DIVERSION CANAL DREDGING	Berkeley	33.347520	-80.100190

In addition, the shipping channel near Charleston, SC is currently authorized to a depth of 45 feet (47-foot deep entrance channel) plus 2 feet of advanced maintenance and 2 feet of allowable overdepth for a total potential dredging depth of 49 feet.

It is highly unlikely current dredging operations are having impacts on adult American shad migration and utilization of historic habitat.

e. The following is a list of land use and mining activities that occurred in 2013 in the Santee River System. Since then, SCDHEC developed an interactive web-based database tool to better assess proposed, ongoing, and/or completed projects. It can be accessed at the following website: https://gis.dhec.sc.gov/watersheds/

Land Application Sites	***Type***	***ND #***	***Section Number***	***Section Name***
TOWN OF ELLOREE	DOMESTIC	ND0067628	03050111-010	(Santee River)
LAKE MARION RESORT & MARINA	DOMESTIC	ND0067610	03050111-010	(Santee River)
SANTEE PSD	DOMESTIC	ND0065676	03050111-010	(Santee River)
SANTEE RESORT HOTEL WWTP	DOMESTIC	ND0067652	03050111-010	(Santee River)
SANTEE LAKES CAMPGROUND	DOMESTIC	ND0067326	03050111-010	(Santee River)
CYPRESS POINT CONDO	DOMESTIC	ND0062227	03050111-010	(Santee River)
SCDPRT/SANTEE STATE PARK	DOMESTIC	ND0067920	03050111-010	(Santee River)

Mining Activities	***Mineral***	***Permit #***	***Section Number***	***Section Name***
MCKENZIE MINE	SAND	1240-19	03050112-060	(North Santee River/South Santee River)
CHARLES CLARK MINE	SAND	1531-19	03050112-060	(North Santee River/South Santee River)
TAYLOR POND MINE	SAND	1544-43	03050112-060	(North Santee River/South Santee River)
GEORGETOWN II QUARRY	LIMESTONE	0885-15	03050112-030	(Santee River)
OLD FIELD MINE	SAND/CLAY	0929-15	03050112-020	(Rediversion Canal)
MINGO MINE #4	CLAY	0712-27	03050111-010	(Santee River)
HILLS-LABRUCE	CLAY	1014-27	03050111-010	(Santee River)
MCCURRY PIT	CLAY	1069-17	03050111-010	(Santee River)

The following is a list of land use and mining activities that occurred in 2013 in the Cooper River System. Since then, SCDHEC developed an interactive web-based database tool to better assess proposed, ongoing, and/or completed projects. It can be accessed at the following website: https://gis.dhec.sc.gov/watersheds/

Mining Activities	*Mineral*	*Permit #*	*Section Number*	*Section Name*
PRIMUS TRACT	SAND/CLAY	0962-15	03050201-050	(Cooper River)
WILLIAMS ASH DISPOSAL	SAND	0964-15	03050201-030	(West Branch Cooper River)
JOHN R. CUMBIE MINE	SAND	0747-15	03050201-010	(Lake Moultrie)
WEEKS MINE	SAND	1488-15	03050201-010	(Lake Moultrie)

Water Quantity				
Water User	*Regulated Cap. (MGD)*	*Pumping Cap. (MGD)*	*Section Number*	*Section Name*
SANTEE COOPER REG. WTR. AUTH.	36	38	03050201-010	(Lake Moultrie)

All land use, mining activities, and water withdrawals that occur in the Santee Cooper River System are closely monitored by the South Carolina Department of Health Environmental Control (DHEC). Therefore, it is highly unlikely these programs impact adult American shad migration and utilization of historic habitat.

f. Atmospheric deposition assessment

Atmospheric deposition is measured as a cooperative effort between many different groups, including federal, state, tribal and local governmental agencies, educational institutions, private companies, and non-governmental agencies as part of the National Atmospheric Deposition Program (NADP). This organization uses many networks (NTN, AIRMoN, MDN, AMNet, and AMNoN) to monitor methyl mercury, ammonia, etc. Detailed information concerning atmospheric deposition in SC can be found at the following website: http://nadp.sws.uiuc.edu/data/annualmaps.aspx

It does not appear that current levels of atmospheric deposition are impacting American shad migrations or utilization of historic habitat.

g. Climate change assessment

A changing climate will present water-related challenges for American shad in several areas including: water quality, water quantity and changes in sea level. Current climate models predict continued warming across the southeast, with the greatest temperature increases projected in summer. Average annual temperatures are projected to rise 4.5°F by the 2080s under a lower emissions scenario and 9°F under a higher emissions scenario with a 10.5°F increase in summer. The frequency, duration and intensity of droughts are likely to continue to increase with higher average temperatures and a higher rate of evapotranspiration. Drought conditions could potentially impact American shad recruitment and long duration drought could negatively impact multiple year classes. Sea level rise is of concern because of the expected change in location of the saltwater/freshwater interface. As sea level rises, saltwater will move further up the river systems of the state thus reducing the amount freshwater spawning habitat available. The amount and distribution of aquatic vegetation also will change in response to increases in salinity, limiting cover and food sources for aquatic organisms. A changing climate will impact the water resources of South Carolina and will present challenges for American shad management.

Action: Develop a climate change plan.

Regulatory Agencies/Contacts: South Carolina Department of Natural Resources (SCDNR)

Goal/Target: Establish recommendations to address climate change.

Progress: A "draft" plan has been developed and is still under review (Appendix 1)

Cost: Unknown at this time.

Timeline: Unknown

h. Competition and predation by invasive and managed species assessment

Aquatic invasive species occur throughout South Carolina's coastal rivers, and non-native ictalurids are some of the most ubiquitous invasive species. Flathead catfish and blue catfish were introduced into South Carolina in 1964 and are now found in all of South Carolina's coastal rivers. A significant portion of blue catfish and especially flathead catfish diet is comprised of fish, and due to their large adult size (>60 lbs) they have the potential to consume both adult and juvenile American shad. Ictalurid population information is currently unavailable for South Carolina's coastal rivers; however current studies are occurring in South Carolina and other neighboring states to assess the potential impacts of non-native catfish on American shad.

Action: Develop an invasive species plan.

Regulatory Agencies/Contacts: South Carolina Department of Natural Resources (SCDNR)

Goal/Target: Establish recommendations to address invasive species.

Progress: SCDNR programs are currently monitoring catch rates of invasive catfish as part of non-targeting sampling and any flat head catfish captured during these activities are being removed from the system. In addition, current eradication programs, such as those on the Satilla River, GA, are being reviewed by SCDNR staff to determine if such programs are feasible for SC Rivers.

Cost: Unknown at this time.

Timeline: Unknown

Edisto River

Habitat Assessment

Two main tributaries of the Edisto River, the North Fork and South Fork begin just south of the piedmont fall line. The main stem river and its two major tributaries amble for 400 km through the Atlantic coastal plain as the longest free flowing black river in South Carolina. During excessive rainy seasons the river inundates lowlands and swamps and the flow basin increases to a mile wide or more.

Historic Habitat

American shad inhabited all of the Edisto River and its major tributaries throughout the 8,161 km^2 watershed (SCDHEC 2013). According to Stevenson (1899), American shad utilized the entire length of both the North and South Fork of the Edisto River, with the reported inland limit to be “sources 300 miles from the coast”.

Current Useable Habitat

Spawning - American shad have access to all adequate habitats in the watershed as there are no barriers to migration. Suitable freshwater riverine channel habitat for spawning in the Edisto River begins approximately at rkm 48 and continues for 143 km to the confluence of the North Fork and South Fork Edisto Rivers. Additionally, McCord (2003) stated that American shad are found for 16 km in the North Fork Edisto River and 48 km of South Fork Edisto River.

Rearing - Suitable rearing habitats are similar to the listed waterways for suitable spawning habitat with the addition of 8,432 ha of estuary in the Edisto River basin (SCDHEC 2013).

Threats Assessment

a. Barriers to migration inventory and assessment

There are no dams on the Edisto River.

b. The following is a list of point source, nonpoint source, mining activities, and water withdrawals that occurred in the Edisto River in 2013. Since then, SCDHEC developed an interactive web-based database tool to better assess proposed, ongoing, and/or completed projects. It can be accessed at the following website: https://gis.dhec.sc.gov/watersheds/

Active NPDES Facilities	*Facility Type*	*Permit Number*	*Section Number*	*Section Name*	*Receiving Stream*
TOWN OF BRANCHVILLE	MINOR DOMESTIC	SC0047333	03050206-01	(Edisto River - Headwaters)	EDISTO RIVER
R. WHALEY DURR/HARTZOG PIT	MINOR INDUSTRIAL	SCG730091	03050206-01	(Edisto River - Headwaters)	CATTLE CREEK
SCE&G/CANADYS STATION	MAJOR INDUSTRIAL	SC0002020	03050206-01	(Edisto River - Headwaters)	EDISTO RIVER
NORTH AMERICAN CONTAINER CORP.	MINOR INDUSTRIAL	SCG250191	03050206-01	(Edisto River - Headwaters)	BETTY BRANCH TRIBUTARY
PETER R. STOKES IV MINE	MINOR INDUSTRIAL	SCG731112	03050206-01	(Edisto River - Headwaters)	EDISTO RIVER
JAY & J CONSTRUCTION INC./BRANCHVILLE PIT MINE	MINOR INDUSTRIAL	SCG731107	03050206-01	(Edisto River - Headwaters)	EDISTO RIVER
REA CONTRACTING LLC/CARROLL PIT #9	MINOR INDUSTRIAL	SCG730656	03050206-01	(Edisto River - Headwaters)	EDISTO RIVER TRIBUTARY
CIRCLE C TRUCK STOP	MINOR INDUSTRIAL	SCG730003	03050206-01	(Edisto River - Headwaters)	EDISTO RIVER
SCDOT/GROVER PIT	MINOR INDUSTRIAL	SCG730517	03050206-01	(Edisto River - Headwaters)	EDISTO RIVER TRIBUTARY
ARGOS CEMENT LLC/HARLEYVILLE CEMENT PLT	MINOR INDUSTRIAL	SC0022586	03050206-02	(Indian Field Swamp)	TOM AND KATE BRANCH
TOWN OF HARLEYVILLE	MINOR DOMESTIC	SC0038504	03050206-02	(Indian Field Swamp)	TOM AND KATE BRANCH
DORCHESTER CO./UPPER DORCHESTER CO. WWTP	MINOR DOMESTIC	SC0025844	03050206-02	(Indian Field Swamp)	POLK SWAMP
SC MINERALS/SANDY RUN MINE	MINOR INDUSTRIAL	SCG730261	03050206-03	(Edisto River/South Edisto River)	SANDY RUN TRIBUTARY
MEM LLC/MIXSON MINE	MINOR INDUSTRIAL	SCG730385	03050206-03	(Edisto River/South Edisto River)	POORLY BRANCH
MURRAY MINES INC./PRINCIP MINE	MINOR INDUSTRIAL	SCG730773	03050206-03	(Edisto River/South Edisto River)	EDISTO RIVER TRIBUTARY
GLOVER REAL ESTATE LLC/COTTAGEVILLE MINE	MINOR INDUSTRIAL	SCG731055	03050206-03	(Edisto River/South Edisto River)	BOSTON BRANCH
SEAFREE EDISTO INC./GOOD HOPE MINE	MINOR INDUSTRIAL	SCG731086	03050206-03	(Edisto River/South Edisto River)	SANDY RUN
DANNY LEE CONSTRUCTION/PIT SAND HILL MINE	MINOR INDUSTRIAL	SCG730976	03050206-03	(Edisto River/South Edisto River)	EDISTO RIVER TRIBUTARY
PALMETTO SAND CO. INC./BINLAW HWY 17A	MINOR INDUSTRIAL	SCG730408	03050206-03	(Edisto River/South Edisto River)	SPOOLER SWAMP
ROGERS & SONS CONSTR. INC./SULLIVANS LANDING	MINOR INDUSTRIAL	SCG730643	03050206-03	(Edisto River/South Edisto River)	SPOOLER SWAMP
JOE WEEKS/DEEP SOUTH MINE	MINOR INDUSTRIAL	SCG731049	03050206-03	(Edisto River/South Edisto River)	ADAMS RUN TRIBUTARY
WEST BANK CONSTR. CO., INC./RED HOUSE POND	MINOR INDUSTRIAL	SCG730657	03050206-03	(Edisto River/South Edisto River)	SANDY RUN
MALPHRUS CONSTR.CO./CRYSTAL LAKES MINE	MINOR INDUSTRIAL	SCG730990	03050206-03	(Edisto River/South Edisto River)	EDISTO RIVER TRIBUTARY
CHARLES HILLS/NICHOLS POND MINE	MINOR INDUSTRIAL	SCG731064	03050206-04	(North Edisto River)	BOHICKET CREEK TRIBUTARY
BEARS BLUFF NATIONAL FISH HATCHERY	MINOR INDUSTRIAL	SC0047848	03050206-04	(North Edisto River)	WEE CREEK
LCP MINING CO. LLC/LEGARE CREEK PLANTATION MINE	MINOR INDUSTRIAL	SC0048488	03050206-04	(North Edisto River)	NORTH EDISTO RIVER
ISLAND CONSTR. CO./TREMONT MINE	MINOR INDUSTRIAL	SCG730128	03050206-04	(North Edisto River)	CHURCH CREEK TRIBUTARY
DIRT SUPPLY LLC/BLUEMEL MINE	MINOR INDUSTRIAL	SCG731001	03050206-04	(North Edisto River)	CHURCH CREEK TRIBUTARY
L. DEAN WEAVER/VANNESS MINE	MINOR INDUSTRIAL	SCG730436	03050206-04	(North Edisto River)	LOWER TOOGOODOO CREEK
RENTZ LANDCLEARING/RENTZ MINE	MINOR INDUSTRIAL	SCG730114	03050206-04	(North Edisto River)	LOWER TOOGOODOO CREEK TRIBUTARY

Nonpoint Source Management Program				
Landfill Facilities	***Status***	***Permit #***	***Section Number***	***Section Name***
HARTZOG PIT	SAND; SAND/CLAY	0412-35	03050206-01	(Edisto River - Headwaters)
P&M MINE	SAND	0950-35	03050206-02	(Indian Field Swamp)
HARLEYVILLE QUARRY	LIME	0110-35	03050206-02	(Indian Field Swamp)
CAW CAW BURROW	SAND	1447-19	03050206-03	(Edisto River/South Edisto River)
RED HOUSE POND	SAND	1568-19	03050206-03	(Edisto River/South Edisto River)
EDINGSVILLE ONE	SAND/CLAY	1090-19	03050206-03	(Edisto River/South Edisto River)

MAD DOG #3 MINE	SAND	1105-35	03050206-03	(Edisto River/South Edisto River)
EDISTO #1	SAND; TOPSOIL	1615-35	03050206-03	(Edisto River/South Edisto River)
DURANT SHELL HOUSE ROAD MINE	SAND; TOPSOIL	1705-19	03050206-03	(Edisto River/South Edisto River)
ADAMS RUN #1 MINE	SAND; TOPSOIL	1770-19	03050206-03	(Edisto River/South Edisto River)
MIXSON MINE	SAND/CLAY	1398-35	03050206-03	(Edisto River/South Edisto River)
HPT BINLAW MINE	SAND; S/CLAY; TOPSOIL	1492-35	03050206-03	(Edisto River/South Edisto River)
PETER J KUHNS		1539-29	03050206-03	(Edisto River/South Edisto River)
SULLIVANS LANDING MINE #2	SAND; SAND/CLAY	1556-35	03050206-03	(Edisto River/South Edisto River)
PRINCIP MINE	SAND; SAND/CLAY	1620-29	03050206-03	(Edisto River/South Edisto River)
PINE BLUFF MINE	SAND/CLAY	1654-35	03050206-03	(Edisto River/South Edisto River)
JOHNS ISLAND #1 MINE	SAND	0122-19	03050206-04	(North Edisto River)
RENTZ MINE	SAND; SAND/CLAY	0994-19	03050206-04	(North Edisto River)
JAMISON MINE	CLAY	0206-19	03050206-04	(North Edisto River)
CEDAR HILL MINE	SAND/TOP SOIL	1694-19	03050206-04	(North Edisto River)
BED ROCK II MINE	SAND/CLAY	1644-19	03050206-04	(North Edisto River)
SHEPPARD C&D LANDFILL	C&D	------	03050206-03	(Edisto River/South Edisto River)

All point source and nonpoint sources that occur in the Edisto River System are closely monitored by the South Carolina Department of Health Environmental Control (DHEC). All discharges are held to water quality standards for the state. Therefore, it is highly unlikely these programs impact adult American shad migration and utilization of historic habitat. In addition, all programs are currently undergoing cooling water intake structures rules (40 CFR 122 and 125) analysis to assess the likelihood of impingement or entrainment in efforts to ensure compliance with the proposed EPA 316(b).

c. Toxic and thermal discharge inventory and assessment-none

d. Channelization and dredging inventory and assessment

The following is a list of historic dredging programs that occurred in the Edisto River System. Since then, USACE developed an interactive web-based database tool to better assess proposed, ongoing, and/or completed projects. It can be accessed at the following website: https://permits.ops.usace.army.mil/orm-public

Start_Date	River	DA_Number	Action_Typ	Project_Na	County	Latitude	Longitude
4/1/1994	Edisto	SAC-1994-10226	SP	EXCAVATION IN OXBOW LAKE	Bamberg	33.230560	-80.849170
5/26/1998	Edisto	SAC-1998-11456	SP	BASIN DREDGING EDISTO ISLAND	Colleton	32.493390	-80.342420
11/16/1999	Edisto	SAC-1999-11853	SP	DREDGING A CANAL	Colleton	32.754500	-80.450700
10/16/2000	Edisto	SAC-2000-13153	NWP	INTAKE DREDGING CANADYS STATION	Colleton	33.065980	-80.623240

It is highly unlikely past dredging operations are causing detrimental impacts on adult American shad migration and utilization of historic habitat.

e. The following is a list of land use and water withdrawal activities that occurred in the Edisto River in 2013. Since then, SCDHEC developed an interactive web-based database tool to better assess proposed, ongoing, and/or completed projects. It can be accessed at the following website: https://gis.dhec.sc.gov/watersheds/

Land Application Sites	*Type*	*ND #*	*Section Number*	*Section Name*
TOWN OF EDISTO BEACH/FAIRFIELD GOLF COURSE	DOMESTIC	ND0063789	03050206-03	(Edisto River/South Edisto River)
JEREMY CAY	DOMESTIC	ND0071510	03050206-03	(Edisto River/South Edisto River)
TOWN OF SEABROOK ISLAND	DOMESTIC	ND0063347	03050206-04	(North Edisto River)
BP FARMS LLC	INDUSTRIAL	ND0087807	03050206-04	(North Edisto River)
BRABHAM DIRT PIT/HOLLYWOOD	INDUSTRIAL	ND0087131	03050206-04	(North Edisto River)

Water Quantity	*REG. CAPACITY (MGD)*	*PUMP. CAPACITY (MGD)*	*Section Number*	*Section Name*
CITY OF CHARLESTON	150	100	03050206-03	(Edisto River/South Edisto River)

All land use and water withdrawals that occur in the Edisto River are closely monitored by the South Carolina Department of Health Environmental Control (DHEC). Therefore, it is highly unlikely these programs impact adult American shad migration and utilization of historic habitat.

f. Atmospheric deposition assessment

Atmospheric deposition is measured as a cooperative effort between many different groups, including federal, state, tribal and local governmental agencies, educational institutions, private companies, and non-governmental agencies as part of the National Atmospheric Deposition Program (NADP). This organization uses many networks (NTN, AIRMoN, MDN, AMNet, and AMNoN) to monitor methyl mercury, ammonia, etc. Detailed information concerning atmospheric deposition in SC can be found at the following website: http://nadp.sws.uiuc.edu/data/annualmaps.aspx

It does not appear that current levels of atmospheric deposition are impacting adult American shad migrations or utilization of historic habitat.

g. Climate change assessment

A changing climate will present water-related challenges for American shad in several areas including: water quality, water quantity and changes in sea level. Current climate models predict continued warming across the southeast, with the greatest temperature increases projected in summer. Average annual temperatures are projected to rise 4.5°F by the 2080s under a lower emissions scenario and 9°F under a higher emissions scenario with a 10.5°F increase in summer. The frequency, duration and intensity of droughts are likely to continue to increase with higher average temperatures and a higher rate of evapotranspiration. Drought conditions could potentially impact American shad recruitment and long duration drought could negatively impact multiple year classes. Sea level rise is of concern because of the expected change in location of the saltwater/freshwater interface. As sea level rises, saltwater will move further up the river systems of the state thus reducing the amount freshwater spawning habitat available. The amount and distribution of aquatic vegetation also will change in response to increases in salinity, limiting cover and food sources for aquatic organisms. A changing climate will impact the water resources of South Carolina and will present challenges for American shad management.

Action: Develop a climate change plan.

Regulatory Agencies/Contacts: South Carolina Department of Natural Resources (SCDNR)

Goal/Target: Establish recommendations to address climate change.

Progress: A “draft” plan has been developed and is still under review (Appendix 1)

Cost: Unknown at this time.

Timeline: Unknown

h. Competition and predation by invasive and managed species assessment

Aquatic invasive species occur throughout South Carolina’s coastal rivers, and non-native ictalurids are some of the most ubiquitous invasive species. Flathead catfish and blue catfish were introduced into South Carolina in 1964 and are now found in all of South Carolina’s coastal rivers. A significant portion of blue catfish and especially flathead catfish diet is comprised of fish, and due to their large adult size (>60 lbs) they have the potential to consume both adult and juvenile American shad. Ictalurid population information is currently unavailable for South Carolina’s coastal rivers; however current studies are occurring in South Carolina and other neighboring states to assess the potential impacts of non-native catfish on American shad.

Action: Develop a invasive species plan.

Regulatory Agencies/Contacts: South Carolina Department of Natural Resources (SCDNR)

Goal/Target: Establish recommendations to address invasive species.

Progress: SCDNR programs are currently monitoring catch rates of invasive catfish as part of non-targeting sampling and any flat head catfish captured during these activities are being removed from the system. In addition, current eradication programs, such as those on the Satilla River, GA, are being reviewed by SCDNR staff to determine if such programs are feasible for SC Rivers.

Cost: Unknown at this time.

Timeline: Unknown

Combahee River

Habitat Assessment

Combahee River is formed at the confluence of Salkehatchie and Little Salkehatchie Rivers and flows 64 km to Saint Helena Sound. Combahee River and its tributaries begin south of the piedmont fall line and flow unimpeded throughout their length (193 km) (McCord 2003). Similar to the Edisto River, Combahee River is characterized by clear tannic acid-stained water flowing across flat, low elevation land.

Historic Habitat

American shad had access to all of the Combahee River and its major tributaries throughout the 3,325 km^2 watershed (SCDHEC 2013). The inland limit of American Shad in the Salkehatchie and Combahee Rivers are not clear, but migrating fish were present near the "source" of the river (Welch 2000). Stevenson (1899) did not distinguish between the two rivers in his report, but did state that "shad ascend a distance of 85 miles" and that the difficulty of ascending the stream prevented him from assessing small fisheries upstream.

Current Useable Habitat

Spawning - American shad have access to all suitable habitats in the watershed as there are no barriers to migration. In the Combahee River, 20 km of suitable freshwater riverine channel spawning habitat is available. In addition, American shad are found for 73 km in the Salkehatchie River (McCord 2003).

Rearing - Suitable rearing habitats are similar to the listed waterways for suitable spawning habitat with the addition of 15,584 ha of estuary in the Combahee River basin (SCDHEC 2013).

Threats Assessment

a. Barriers to migration inventory and assessment

There are no dams on the Combahee River.

b. The following is a list of point source facilities that occurred in the Combahee River in 2013. Since then, SCDHEC developed an interactive web-based database tool to better assess proposed, ongoing, and/or completed projects. It can be accessed at the following website: https://gis.dhec.sc.gov/watersheds/

Active NPDES Facilities	Facility Type	Permit Number	Section Number	Section Name	Receiving Stream
TOWN OF YEMASSEE	COMBAHEE RIVER	SC0025950	DOMESTIC	03050207-07	(Combahee River)

All point source and nonpoint sources that occur in the Combahee River System are closely monitored by the South Carolina Department of Health Environmental Control (DHEC). All discharges are held to water quality standards for the state. Therefore, it is highly unlikely these programs impact adult American shad migration and utilization of historic habitat. In addition, all programs are currently undergoing cooling water intake structures rules (40 CFR 122 and 125) analysis to assess the likelihood of impingement or entrainment in efforts to ensure compliance with the proposed EPA 316(b).

c. Toxic and thermal discharge inventory and assessment-none

d. Channelization and dredging inventory and assessment

The following is a list of historic dredging programs that occurred in the Combahee River System. Since then, USACE developed an interactive web-based database tool to better assess proposed, ongoing, and/or completed projects. It can be accessed at the following website: https://permits.ops.usace.army.mil/orm-public

Start_Date	River	DA_Number	Action_Typ	Project_Na	County	Latitude	Longitude
4/26/1994	Combahee	SAC-1994-10243	SP	MILL POND MAINTENANCE	Colleton	32.677780	-80.686110
7/14/1999	Combahee	SAC-1999-15974	NWP	COMBAHEE LANDING SILT REMOVAL	Hampton	32.706230	-80.827530

It is highly unlikely past dredging operations are causing detrimental impacts on adult American shad migration and utilization of historic habitat.

e. Land use inventory and assessment-none

f. Atmospheric deposition assessment

Atmospheric deposition is measured as a cooperative effort between many different groups, including federal, state, tribal and local governmental agencies, educational institutions, private companies, and non-governmental agencies as part of the National Atmospheric Deposition Program (NADP). This organization uses many networks (NTN, AIRMoN, MDN, AMNet, and AMNoN) to monitor methyl mercury, ammonia, etc. Detailed information concerning atmospheric deposition in SC can be found at the following website: http://nadp.sws.uiuc.edu/data/annualmaps.aspx

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Cost: Unknown at this time.

Timeline: Unknown

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Cost: Unknown at this time.

Timeline: Unknown

Fish Passage Considerations

The 2020 Atlantic States Marine Fisheries Commission's American Shad Stock Assessment and Peer Review Report provides an extensive review of available literature and discussion on the topic of fish passage (ASMFC 2020). Specifically, it highlights the issues with lack of evaluation and performance from decades-old approaches, facilities designs/operations that are not effective, and therefore cannot reasonably be expected to achieve management and restoration goals without significant changes. The Assessment Report also provides an important quantitative modeling approach examining shad habitat and passage barriers, and the need to address status quo fish passage performance. The impacts of these barriers and status quo passage are described and also modeled as effects on spawner population size under three scenarios, 1) no barriers, 2) first barrier with no passage, and 3) realistic fish passage performance measures applied to barriers (e.g., upstream passage efficiency of 50%).

The Assessment Report used standardized data and modelling approaches that quantified the impacts of barriers and fish passage as significant in all three management areas examined based on shad life history and habitat (New England, Mid-Atlantic, and South Atlantic). The assessment determined that overall, dams completely or partly block nearly 40% of the total habitat once used by American Shad. The model results of the "no barriers" scenario yielded an estimated spawner production potential 1.7 times greater than that yielded by the scenario assuming no passage at the first barrier: 72.8 million versus 42.8 million fish. The results of the third model scenario, which applies "realistic" (i.e., current) fish passage efficiencies, resulted in a gain of less than 3 million fish. Conclusions include "losses in (spawner production) potential are significant in each state and region." The Assessment Report provides a strong justification for the need and benefits of requiring improved fish passage performance measures. Additionally, meeting such improved passage performance standards is now an achievable goal given the current state of knowledge on fish behavior, swimming performance, and fish passage engineering expertise.

References

Burns, F. 1887. Rockfish in South Carolina. Bulletin U.S. Fish Commission (1886) 6: 18pp.

McCord, J. W. 2003. Alsosid Habitats for South Carolina Watersheds. South Carolina Department of Natural Resources. Diadromous Fisheries Program, Office of Fisheries Management, Marine Resources Division. Charleston. 6 pp.

South Carolina Department Health and Environmental Quality, 2013. http://www.scdhec.gov/environment/water/shed/shed.htm.

Stevenson, C. H. 1899. The shad fisheries of the Atlantic coast of the United States. Report of the Commissioner, U.S. Commission of Fish and Fisheries. 29: 103-269 pp.

Welch, S. M. 2000. A Report on the Historical Inland Migrations of Several Diadromous Fishes in South Carolina Rivers. Clemson University, Department of Aquaculture, Fisheries and Wildlife. 19 pp.

Appendix 1. SCDNR Climate Change document

DNR

CLIMATE CHANGE IMPACTS TO NATURAL RESOURCES IN SOUTH CAROLINA

This document is available on the Department of Natural Resources web site at http:www.dnr.sc.gov/

FOREWORD

In recent years state natural resource agencies including the South Carolina Department of Natural Resources (DNR) have been engaged in discussions about climate change. Staff at DNR, and many of our counterpart state agencies, are routinely asked some of the following questions:

1. What might happen to our fish, wildlife and marine resources if climate change should have an effect on them?
2. Are invasive and noxious species likely to be able to exploit subtle changes in air or water temperature or water quality or quantity?
3. What impact might climate change have on water resources and its continued availability for both humans and fish and wildlife?
4. What are some of the common-sense things we can do to adapt to climate change if it begins to occur?
5. How might recreational boating be affected if our lakes and reservoirs are impacted by climate change?
6. What monitoring programs are in place that will enable us to be able to predict impacts to natural resources or recreational use before they occur?
7. What technologies are necessary to enable science-based natural resource monitoring programs?

These are just a few of the questions we must consider given our mandate to be the stewards of natural resources in South Carolina. In reality, there are many more questions and none of them have easy answers. Facing complex issues and preparing for an uncertain future are nothing new to the DNR. We utilize a sound, science-based approach and have been doing this for many decades. DNR does not have experts in the field of climate change or personnel involved in pure climate change research. However, scientists, biologists, and other personnel from DNR have reviewed the available scientific literature on climate change and the possible impacts on the state's natural resources and drafted a guidance document to help us navigate the path forward.

Over the past few decades scientists have documented melting glaciers, diminishing polar sea ice, shifting of growing seasons, changes in migratory patterns of birds and fish, rising sea levels and many other climate-related phenomena. These changes and countless more like them may have substantial consequences for both the environment and the economy. Nationally, hunting, fishing and wildlife-related recreation alone add $122 billion to the economy each year. In South Carolina, natural resources are essential for economic development and contribute nearly $30 billion and 230,000 jobs to the state's economy. Access to abundant recreational opportunities and natural assets play an important role in economic growth and quality of life at the local, regional and state levels, so protection and enhancement of our natural resources can and should be part of our overall economic development strategy.

Any changes to our coastal environment could cause substantial economic consequences. Shoreline changes affect property uses, land values, tourism, and natural resources management as well as traditional uses such as hunting and fishing, timber management and agriculture.

Some have argued that natural variability and chance have the major influences over climate change, that this is a natural process, and that climate scientists have been overreacting. At DNR, we do not profess to know why all of these changes seem to be occurring, but we do understand that we have a responsibility to stay abreast of the latest science as we strive to make the best decisions possible in the management of the state's natural resources.

All of these potential impacts require a science-based approach to decision making. Moving forward, we should develop an efficient strategy incorporating baseline measurements, monitoring, and data analyses to provide decision makers accurate assessments and predictions of future environmental changes. We know that we must be prepared for change should it occur.

This report is a first step in the process of identifying and gathering published information on how climate change may affect wildlife, fisheries, water supply and other natural resources in South Carolina. We have identified some key adaptive steps necessary to respond to potential climate change in our state. This report is being released for public review, and we invite our citizens and leaders to participate by providing their comments. Public comments may be submitted electronically to climatechange@dnr.sc.gov or by mail to Climate Change, PO Box 167, Columbia, SC 29202. We will appreciate receiving your comments by May 24, 2013.

Signature:

Alvin A. Taylor
Director

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<u>Law Enforcement</u>
Van McCarty
Karen Swink

<u>Land and Water Conservation</u>
Barry Beasley, PhD
Scott Howard, PhD
Masaaki Kiuchi, PhD
Hope Mizzell, PhD

<u>Marine</u>
Steve Arnott, PhD
Robert Chapman, PhD
Rebekah Walker
David Whitaker

<u>Outreach and Support Services</u>
Monica Linnenbrink
Jim Scurry, PhD

<u>Wildlife and Freshwater Fisheries</u>
Lynn Quattro
Derrell Shipes
Ross Self
Vivianne Vejdani

<u>Executive</u>
Bob Perry
Kevin Kibler

Staff listed above constituted the South Carolina Department of Natural Resources Climate Change Technical Working Group, and they collaborated to provide direction and copy for this document. We are very grateful both to Ann Nolte who reviewed two versions of this document and provided very capable editorial assistance and also to Kay Daniels and Ivetta Abramyan who assisted the effort in many ways.

Bob Perry
Compiler and Editor

DEFINITIONS

Sources:

1. Glossary of Terms used in the IPCC Fourth Assessment Report.[1]
2. American Geological Institute, Glossary of Geology.[2]
3. NOAA.[3]
4. Climate Literacy.[4]

Adaptation – Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, moderating harm or exploiting beneficial opportunities.

Albedo – The fraction of solar radiation reflected by a surface or object, often expressed as a percentage. Snow-covered surfaces have a high albedo; the albedo of soils ranges from high to low; vegetation-covered surfaces and oceans have a low albedo. The Earth's albedo varies mainly through varying cloudiness, snow, ice, leaf area and land cover changes.

Anadromous – Migration of aquatic organisms from the sea to freshwater to spawn.

Anthropogenic – Effects, processes or materials that are derived from human activities, as opposed to those occurring in biophysical environments without human influence. Resulting from or produced by human beings.

Assemblage – The smallest functional community of plants or animals.

Atmosphere – The mixture of gases surrounding the Earth, retained by gravity. It protects life by absorbing ultraviolet solar radiation, warms the surface through heat retention (the greenhouse effect), and reduces temperature extremes between day and night.

Benthic – Relating to the bottom of a sea or lake or to the organisms that live there.

Catadromous – Migration of aquatic organisms from freshwater to the sea to spawn.

Climate – The characteristic weather of a region, particularly as regards temperature and precipitation, averaged over some significant interval of time. Climate in a narrow sense is usually defined as the average weather, or more rigorously, as a statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the *climate system*. In various parts of this report different averaging periods, such as a period of 20 years, also are used.

Climate change – Climate change refers to a change in the state of the climate that can be identified, for instance by using statistical tests, by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal

[1] http://www.ipcc.ch/publications_and_data/publications_and_data_glossary.htm. Last accessed Jan 2011.
[2] http://www.agiweb.org/pubs/glossary/. Last accessed May 2011.
[3] http://www.weather.gov/glossary/. Last accessed Mar 2011.
[4] https://gcce.larc.nasa.gov/index.php?q=resources/climate-literacy&page=7. Last accessed Apr 2011.

processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

Climatology – The study of climate, the long-term average of conditions in the atmosphere, ocean, and ice sheets and sea ice described by statistics, such as means and extremes.

Demersal – Refers to species living near the benthic, or bottom, zone of the sea.

Diadromous – Migration of aquatic organisms between fresh and salt waters; includes both anadromous and catadromous.

Ecological services – Humankind benefits from a multitude of resources and processes supplied by natural ecosystems including products such as clean drinking water and processes such as decomposition and assimilation of wastes.

Endangered species – A species of flora or fauna whose numbers are so small that the species is at risk of extinction.

Evapotranspiration – The sum of water vapor evaporated from the Earth's surface and transpired from vegetation to the atmosphere from sources such as the soil, forest canopy interception and surface waters.

Feedback mechanism - A loop system in which the system responds to a change either in the same direction (positive feeback) or in the opposite direction (negative feedback).

Fossil fuel – A general term for any hydrocarbon that may be used for fuel, chiefly coal, petroleum and natural gas formed by decomposition and compression of buried dead organisms.

Glacial maximum – The time or position of the greatest advance of a glacier, or of glaciers.

Greenhouse effect – The natural effect produced as greenhouse gases allow incoming solar radiation to pass through the Earth's atmosphere, but prevent most of the outgoing infrared radiation from the surface and lower atmosphere from escaping into space. Life on Earth could not be sustained without the natural greenhouse effect. However, if the atmospheric concentrations of these greenhouse gases rise, the average temperature of the lower atmosphere will gradually increase.

Greenhouse gas (GHG) – The gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. Water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. There are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine and bromine containing substances.

Habitat – An ecological, environmental or physical area inhabited by a particular species of animal, plant or other organism.

Insolation – A measure of the amount or rate of solar radiation (Sun) energy received on a given surface area in a given time. **IN**cident **SOL**ar radi**ATION**

Last glacial maximum (LGM) – The time of maximum extent of the ice sheets during the last glacial period, 18,000 years ago. For the central and eastern United States this is referred to as the Wisconsin glaciations. The most recent glacial period lasted from 110,000-11,700 years ago, during the Pleistocene. The

Holocene begins at the end of the Pleistocene, and is considered an interstadial in Quaternary/Pleistocene glaciations.

Little Ice Age – An interval of time between approximately AD 1400-1900 when temperatures in the Northern Hemisphere generally were colder than today, especially in Europe. Originally employed for a mid-Holocene event in the Yosemite area, California, about 3,000 years BC.

Medieval Warm Period (MWP) – An interval of time between AD 1000-1300 in which some Northern Hemisphere regions were warmer than during the Little Ice Age that followed.

Milankovitch theory – An astronomical theory of glaciation, formulated by Milutin Milankovitch, Yugoslav mathematician, in which climatic changes result from fluctuations in the seasonal and geographic distribution of insolation, determined by variations of the Earth's orbital elements, namely eccentricity, tilt of rotational axis and precession. It is supported by recent radiometrically dated reconstructions of ocean temperature and glacial sequences.

Mitigation – An anthropogenic intervention to reduce the anthropogenic forcing of the climate system including strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks.

Outgassing –The release of trapped or embedded gases

Paleoclimate Proxies – A proxy climate indicator is a local record that is interpreted, using physical and biophysical principles, to represent some combination of climate-related variations back in time. Climate-related data derived in this way are referred to as proxy data. Examples of proxies include pollen analysis, tree ring records, characteristics of corals and various data derived from ice cores.

Paleoclimatology – The study of climate during periods prior to the development of measuring instruments, including historic and geologic time, for which only proxy climate records are available.

Paleotempestology – The study of past tropical cyclone activity (hurricanes) by means of geological proxies and historical records.

Pleistocene – The earlier of 2 Quaternary epochs, extending from the end of the Pliocene, about 1.8 million years ago, until the beginning of the Holocene, about 11,600 years ago.

Sea-level rise – The contextual relationship between land and the sea when the surface of the sea is increased in height relative to land due to increased water volume of the ocean and/or sinking of the land.

Sequestration – The removal and storage of carbon from the atmosphere in carbon sinks (such as oceans, forests or soils) through physical or biological processes, such as photosynthesis.

Stadial – A short period of colder temperatures during an interglacial (warm period) separating the glacial periods of an ice age. It can be marked by a glacial readvance. The Little Ice Age is a stadial event. This is opposite of an interstadial, which is a short, warm period occurring within a longer glacial period and is marked by a temporary glacial retreat.

Teleconnections – Refers to a recurring and persistent large-scale pattern of pressure and circulation anomalies spanning vast geographical areas. Teleconnection patterns also are referred to as preferred modes of low-frequency (or long time scale) variability. Although these patterns typically last for several weeks to several months, they sometimes can be prominent for several consecutive years, thus reflecting an important part of both the interannual and interdecadal variability of the atmospheric circulation. Many of the teleconnection patterns also are planetary-scale in nature, and span entire ocean basins and continents. For example, some patterns span the entire North Pacific basin, while others extend from eastern North America to central Europe. Still others cover nearly all of Eurasia. They are climate anomalies that are related to each other but occur at large distances from each other perhaps scanning thousands of miles.

Threatened species – A species likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.

Troposphere – The lowest portion of Earth's atmosphere, from the surface to about 10 km in altitude at mid-latitudes (ranging from 9 km at high latitudes to 16 km in the tropics on average), where clouds and weather phenomena occur. In the troposphere, temperatures generally decrease with height. It contains approximately 75% of the atmosphere's mass and 99% of its water vapor and aerosols**.**

Vostok Ice Core – In January 1998, this ice-drilling project, a collaborative between Russia, the United States and France at the Russian Vostok station in East Antarctica yielded the deepest ice core ever recovered, reaching a depth of 3,623 m. Preliminary data indicate the Vostok ice-core record extends through four climate cycles, with ice slightly older than 400,000 years ago.

Water supply – The total amount of water within a defined area that is available for human and other uses.

Wisconsin Glaciation or Wisconsin Stage – the classical fourth glacial stage (and last) of the Pleistocene Epoch in North America. It followed the Sangamon Interglacial Stage and preceded the current Holocene Epoch.

Younger Dryas – A period 12,900-11,600 years ago, during the deglaciation, characterized by a temporary return to colder conditions in many locations, especially around the North Atlantic.

ACRONYMS AND ABBREVIATIONS

ACE Basin – Ashepoo, Combahee and Edisto rivers basin
ASMFC – Atlantic States Marine Fisheries Commission
AMO – Atlantic Multi-Decadal Oscillation
BMRI – Baruch Marine Research Institute, of the University of South Carolina
CO_2 – Carbon dioxide
COR – Coastal Reserves and Outreach of the MRD
CWCS – Comprehensive Wildlife Conservation Strategy
DHEC – South Carolina Department of Health and Environmental Control
DNR – South Carolina Department of Natural Resources
ENSO – El Niño-Southern Oscillation
FAA – Federal Aviation Administration
GIS – Geographic Information Systems
GHG – Greenhouse gas
GSP – Greenville-Spartanburg Airport National Weather Service Station
HAB – Harmful Algal Bloom
LED – Law Enforcement Division of DNR
LGM – Last Glacial Maximum
LWC – Land, Water and Conservation Division of DNR
MARMAP – Marine Resources Monitoring, Assessment and Prediction Program
MJO – Madden-Julian Oscillation
MRD – Marine Resources Division of DNR
MRRI – Marine Resources Research Institute, of MRD
NGO – Non-governmental organization
NOAA – National Oceanic and Atmospheric Administration
NWS – National Weather Service
OFM – Office of Fisheries Management of MRD
QBO – Quasi-Biennial Oscillation
SAB – South Atlantic Bight
SAMFC – South Atlantic Marine Fisheries Council
SEAMAP – Southeast Area Monitoring and Assessment Program
SENRLG – Southeast Natural Resource Leadership Group
SERTC – Southeastern Regional Taxonomic Center
USC – University of South Carolina, National Weather Service Station
USGS – United States Geological Survey
USHCN – United States Historical Climatology Network
WFF – Wildlife and Freshwater Fisheries Division of DNR

CONTENTS

EXECUTIVE SUMMARY

Global warming and cooling have occurred naturally throughout history, but changes in the past were usually much slower than the rate of warming that has occurred in the last few decades. Both land and ocean temperature measurements independently indicate a warming trend since around 1880, but since 1979, land temperatures have increased approximately twice as fast as ocean temperatures (0.25 °C per decade versus 0.13 °C per decade). Since the mid 1970s, the average surface temperature has increased by about 1°F (0.56 °C). If this trend continues, by the end of this century, average global temperature is projected to rise between 2-11.5ºF (1.1-6.4°C). Observed climate-related changes are expected to continue, and are likely to result in new natural resource impacts and changes that potentially disrupt or damage ecological services, water supplies, agriculture and forestry, fish and wildlife species and their habitats, endangered species and commercial and recreational fishing and hunting.

The South Carolina Department of Natural Resources (DNR) is charged by law with the management, protection and enhancement of natural resources in South Carolina and thus is the steward of the state's natural resources for their use and enjoyment by the public. In South Carolina, natural resources are essential for economic development and contribute nearly $30 billion and 230,000 jobs to the state's economy. The DNR recognizes the need to address potential climate change as a threat-multiplier that could create new natural resource concerns, while exacerbating existing tensions already occurring as a result of population growth, habitat loss, environmental alterations and overuse. Thoughtful and careful planning regarding climate change is needed in order to protect the valuable natural resources of the Palmetto State. In response to these challenges, DNR has identified potential impacts of climate change on the natural resources of South Carolina, and developed an adaptive response strategy to offset, minimize or delay the effects of a changing climate on natural resources. The agency will:

1. Gather factual, accurate information and data on how climate change may affect wildlife, fisheries, water supply and other natural resources within the state,
2. Identify monitoring and data needs required to assess impacts of climate change in the state,
3. Use factual information, data, research and modeling to determine what actions need to be taken to address climate change,
4. Ensure data quality; provide original research that addresses information needs; and validate modeling results with collected data,
5. Identify opportunities to partner with other state agencies and academic institutions where needed to accomplish this mission,
6. Identify ways for state officials, local government and citizens to assist in mitigation of or adaptation to natural resource impacts related to climate change, and
7. Locate and obtain available funding to assist in meeting agency mission and goals related to climate change.

Climatology is the study and analysis of weather records over an extended period of time. The study of climate prior to the use of instrumental records is known as paleoclimatology. Results from paleoclimate studies indicate that climate variation is a natural phenomenon; Earth's climate has changed many times throughout history. Currently, we are in an interglacial, or warm, period, which began at the end of the last glacial maximum 13,500 years ago. Other results from paleoclimate studies show that climate has changed episodically on a variety of timescales, and some of these changes have occurred quite abruptly. Climate has varied through time under the influence of its own internal dynamics involving changes such as volcanic eruptions and solar variations. Now, human-caused changes in atmospheric composition appear to be influencing climate change.

To date, no systematic study of South Carolina's paleoclimate has been completed. Some studies have addressed climatic conditions at a specific time or at a specific site, but no studies document the state's climate before instrumental records became available. The state's paleoclimate record should be studied at several time scales to establish a baseline for current climatic conditions and future trends. South Carolina climatological trend data, 1895-2010, has been analyzed and shows a warming trend that started during the 1970s continuing to the present. A warming trend was also observed in winter coastal water temperatures during a study performed from 1950-2010. Severe weather is a persistent feature of South Carolina's climatology. No discernible relation is seen between the number of tornadoes or coastal hurricanes land falls and the aforementioned warming trends.

Current climate models predict continued warming across the southeast, with the greatest temperature increases projected in summer. Average annual temperatures are projected to rise 4.5°F by the 2080s under a lower emissions scenario and 9°F under a higher emissions scenario with a 10.5°F increase in summer. The frequency, duration and intensity of droughts are likely to continue to increase with higher average temperatures and a higher rate of evapotranspiration.

Sea level rise is a serious concern in South Carolina due to our extensive coastline. Sea level rise will affect coastal habitats such as estuaries, creeks, marshes, managed wetlands, hammocks, sand dunes and beaches by modifying patterns of sea water encroachment, flooding, erosion and deposition. It will also affect fish and wildlife species that depend on these habitats, as well as any related activities such as fishing, hunting and tourism. Some habitats may adapt by depositional growth or inland migration, but coastal development could impede the latter in many areas. Potential management responses include inland retreat, coastal reinforcement and beach nourishment, but each option has ecological and economic costs.

A changing climate will present water-related challenges in several areas to include water quality, water quantity and changes in sea level. Rainfall and streamflow are tied directly to seasonal climatic conditions. Although DNR has no direct responsibility in regulating water quality, issues of water quality and quantity are difficult to separate when availability is in question. By statute DNR is responsible for water planning in

South Carolina. A comprehensive statewide water policy is needed to maintain and preserve surface- and ground-water supplies. Basic information needed for this work is lacking or threatened due to limited funding. Necessary steps are required to maintain and expand the availability of reliable information needed for a water assessment. Sea-level rise, drought and flooding are occurring, and sea-level rise already is creating shoreline change. Several drought periods in recent years have adversely affected agricultural interests, forestry and water supply. Planning and monitoring is needed prior to and during drought events. A predicted result of climate change is the increase in intense storm events causing greater water inputs in shorter periods of time, affecting flood frequency and duration.

Temperature rise is expected to affect a number of natural resource issues in South Carolina. Habitats and life histories of species within the state may be shifted both in terms of time and space. This could result in changes to feeding and nesting areas as well as reproductive cycles. Additionally, ecosystem-wide regime shifts may result in major changes in species diversity and interactions at all trophic levels. Temperature has a direct effect on the physiology and survival of aquatic species. Commercial and recreational landings of aquatic species may be affected when life histories shift. Ranges for species may shift so they no longer occur in South Carolina, while other more temperature tolerant species may thrive where they had not done so previously. Harmful algal blooms caused by certain species of microscopic, photosynthetic algae can cause a wide range of detrimental effects that are species-specific. These effects may include shading and destruction of estuarine grass habitat, shellfish poisoning and toxin production that can bioaccumulate in the food chain potentially inducing sickness and death in wildlife and humans. Increasing temperatures can reduce oxygen levels in coastal waters through a variety of mechanisms such as a decrease in the solubility of oxygen, an increase in productivity and stratification of the water column. These factors can result in dead zones in coastal and estuarine waters. Increasing ocean acidification is related to increasing carbon dioxide levels in the Earth's atmosphere. Ocean acidification (decreasing Ph) raises concerns about the future of coral reefs and other species that incorporate calcium carbonate into their skeletons including mollusks, crustaceans and some plankton.

Habitat decline, a shifting climate regime, increasing development, particularly in coastal areas, and rising sea level represent constraints and barriers to dispersal and migration of fish, wildlife and plant species. Maintenance of migratory corridors is essential for the ability of wildlife and fish to find suitable habitat and for population maintenance. Temperature changes likely will change the vegetative structure of wildlife habitats throughout the state. Habitat loss not only affects the area in which the species can live, it also affects food availability and availability of suitable nesting and breeding areas. Impacts associated with temperature changes most likely will be greater in the higher elevations of the state. Precipitation changes will affect both surface and groundwater levels and will result in impacts to both terrestrial and aquatic systems. As the nation strives to locate and develop alternative, cleaner and more carbon-neutral sources of energy, it is important to understand that such energy sources may result in additional impacts to wildlife, fish and their habitats.

Species of greatest conservation need are identified in the *South Carolina Comprehensive Wildlife Conservation Strategy*; these include endangered and threatened species and species of concern. Although DNR has collected some short- and long-term information relative to some of these species and their habitats, the collective database is insufficient to understand the role of climate change in the population trends of these species. It also is difficult to identify conservation actions needed to offset or mitigate the effects of climate change. DNR should strengthen and standardize the inventory and monitoring of greatest conservation need species and their habitats.

Increased temperatures, changes in rainfall and other environmental factors affected by climate shifts can create ideal conditions for proliferation of invasive plant and animal species, including parasites and pathogens. Regardless of the manner in which they have become established, these species already are affecting native animals and their habitats. As climate changes, we likely will see an increase of exotic species migrating to South Carolina. Habitats can be destroyed as resources are over-utilized. Invasive and non-indigenous species have the potential to outcompete native species for food and other resources. Species currently located in Florida and southern Georgia that come from more temperate parts of the world have been historically limited to ranges south of South Carolina by cold winters. They are now of major concern. Significant climate change could allow range expansion in these exotic species that would be detrimental to native species.

Climate warming has been linked with a general increase in pathogens of marine, aquatic and terrestrial organisms. This may negatively impact the populations of certain species, including some of economic importance.

Wildlife and fish populations likely will be altered as climate change occurs. While such changes may lead to a reduction of commercial and recreational hunting and fishing opportunities of some species, other opportunities may increase for those species which could benefit from an altered climate. Regardless of whether climate change produces commercial and recreational winners or losers, it will be important for DNR to implement long-term monitoring of harvested species in order to detect temporal and spatial changes in numbers and prevent unsustainable population declines. Further, it will be important for DNR to keep the public and policy makers informed, through outreach and education efforts, of changes as they occur in order to reduce the potential for conflict between human and natural resource needs.

A critical element of the agency's response to climate change is to increase public awareness of the potentially adverse and positive effects resulting from these changes. Agency efforts at outreach and education are first, to strengthen and increase partnerships with other agencies and organizations involved in climate change research and policy and planning; second, to assist local communities in planning for change, such as providing coastal resiliency to reduce overall vulnerability of economic and ecological systems to climate variations; and, third, to communicate information on climate change to citizens of South Carolina using the World Wide Web and public forums. Additionally, scientific research results will be published in peer-reviewed journals.

In order to meet the agency's long-term ability to respond to climate change impacts in South Carolina, numerous additional strategies and technologies will be required. First, DNR should implement a resource inventory and monitoring program to track trends in resource abundance and distributions at the species and landscape level. Second, the agency must expand its technology infrastructure to support the climate change studies including implementing various direct and remotely-sensed measurement platforms to provide *in situ* documentation of critical climate change parameters and the integration of these data into a comprehensive database. Third, DNR must develop appropriate data access, scientific analysis and resource management decision-support tools to assess climate change impacts and to develop appropriate resource management strategies. Fourth, DNR must develop the expertise required to meet the challenges of understanding and addressing the vast array of environmental impacts and natural resource management issues associated with climate change. Staff training in various analytical, modeling and geographic information systems software, and associated technologies is essential.

This report identifies the overriding natural resource issues and provides recommended actions to keep South Carolina at the forefront of conserving natural resources during an era of changing climate. These overarching issues include the potential for:

1. Detrimental change in habitat,
2. Detrimental change in abundance and distribution of species,
3. Detrimental change in biodiversity and ecosystem services,
4. Detrimental change to the traditional uses of natural resources,
5. Detrimental change in the abundance and quality of water, and
6. Detrimental change in sea level.

Specific tasks identified by DNR in order to move forward in an era of climate change while protecting natural resources include:

1. Spatial mapping,
2. Monitoring and establishing living and non-living resources and climate trends,
3. Habitat acquisition,
4. Adaptation strategies on DNR-titled properties,
5. Integration and analysis of data,
6. Outreach and education,
7. Developing additional partnerships and collaborating with others, and
8. DNR leading by example.

DNR is making climate change an integral part of the agency's ongoing mission by integrating climate change into the DNR organizational culture, its structure and all aspects of its work. These key steps include:

1. Develop an approach that will incorporate climate change into DNR strategic and operational plans and existing structure to be used as a vehicle for internal and external communication,
2. Ensure that all levels of agency staff are aware of and engaged in climate-change initiatives,
3. Update and align DNR actions with regional and national climate change initiatives as appropriate,
4. Work with stakeholders and partners on fish, wildlife and habitat adaptation and mitigation,
5. Prepare an internal and external outreach strategy to communicate climate change issues, and
6. Develop clear and measurable indicators to track the results of DNR climate change efforts.

To accomplish its mission, DNR recommends the following core climate change efforts:

1. Policies and Opportunities – focus on grants, legislation, partnerships and strategic planning,
2. Research and Monitoring – focus on standardized monitoring protocols and state-specific data (including gaps) and predictive modeling,
3. Communication and Outreach – focus on the DNR messages and a climate change communication plan,
4. Adaptation – focus on the activities related to unavoidable climate change impacts on natural resources
5. Operations – focus on positioning DNR as a leader by reducing the agency's carbon footprint, improving its energy efficiency and decreasing operational costs.
   a. Achieve increased fuel economy through various methodologies.
   b. Achieve increased energy efficiency through energy audits and adoption of practicable energy audit recommendations.
   c. Implement practicable water efficiency measures for agency buildings.
   d. Implement paperless internal communications and document management.

DNR is taking a lead role among South Carolina state agencies to advance the scientific understanding of the vulnerability of South Carolina's vital natural resources during an era of changing climate. This will enable the agency, its partners, constituents and all Palmetto State citizens to avoid or minimize the anticipated impacts while protecting South Carolina's natural resources.

TABLES

FIGURES

1.0 INTRODUCTION

1.1 Climate Change

Climate change, such as global warming and cooling, has occurred naturally throughout history over timescales that vary from decades to hundreds of thousands of years. However, changes in the past were usually much slower than the rate of warming that has been measured in the last few decades. Figure 1.1 provides the annual global temperature anomalies for the past 130 years, including both land and ocean temperature trends. Land temperatures increase faster than ocean temperatures due to the greater heat capacity of the ocean and its ability to transfer more heat to the atmosphere in the form of evaporative cooling.[5] Both land and ocean temperature measurements independently indicate a warming trend since around 1880, but since 1979, land temperatures have increased approximately twice as fast as ocean temperatures (0.25 °C per decade versus 0.13 °C per decade)[6]. Although temperature changes vary over the globe, since the mid 1970s, the average surface temperature has increased by about 1°F (0.56 °C) [7]. If this trend continues, by the end of this century, average global temperature is projected to rise between 2-11.5ºF (1.1-6.4°C)[8].

While some of this warming has a natural cause, there is evidence that human activity is disproportionally contributing to the measured warming. The concern over human activities arises primarily from fossil fuel combustion, which releases carbon dioxide and other greenhouse gases, and changes in land use. The introduction of external greenhouse gases into the atmosphere alters the radiative balance of the earth by changing its atmospheric composition, which enhances the natural greenhouse effect. There are complex interactions between many of these processes.

The increase in global temperatures is just one consequence of a changing climate. The various components of the climate and earth system are linked through complex feedback mechanisms, so that a change in one component, such as temperature, can induce changes and adjustments in other components. Changes already observed, or projected to occur, include sea level rise; changes in rainfall patterns; increases in

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[5] Rowan T. Sutton, Buwen Dong, Jonathan M. Gregory (2007). "Land/sea warming ratio in response to climate change: IPCC AR4 model results and comparison with observations". *Geophysical Research Letters* **34** (2).

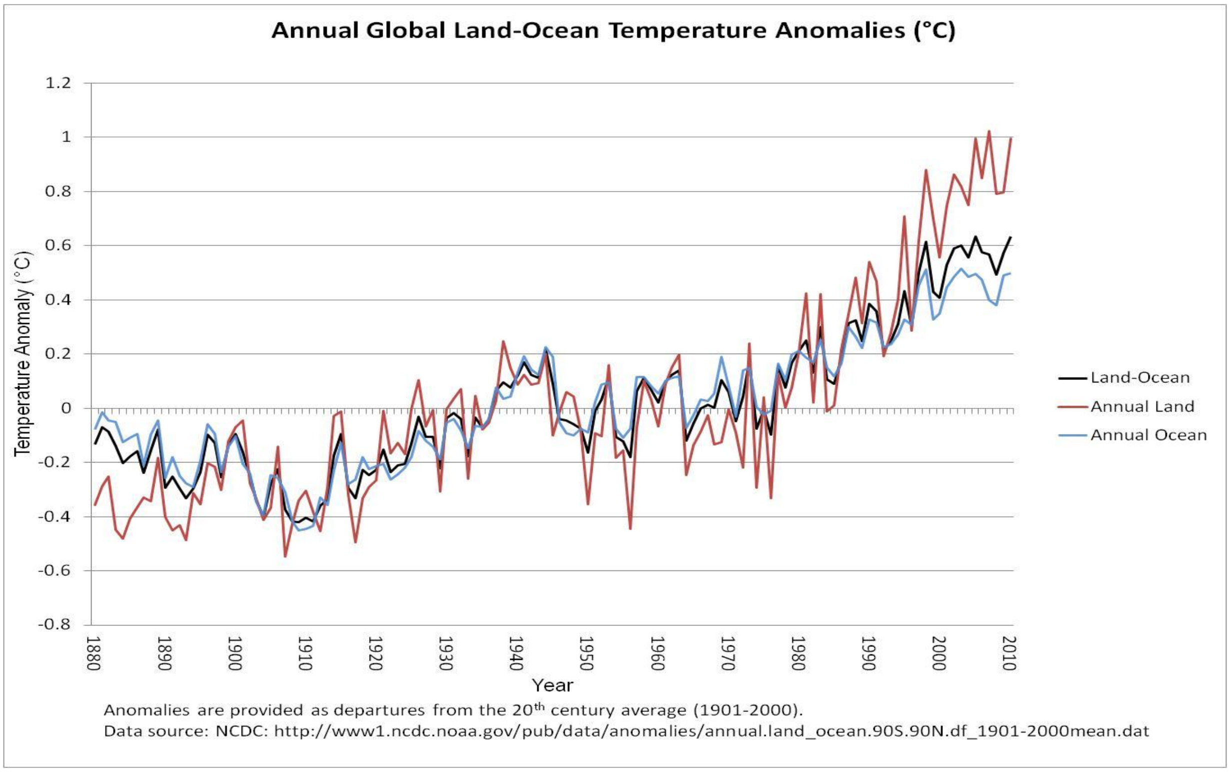
[6] Chapter 3, p. 237, in IPCC AR4 WG1 (2007). Solomon, S.; Qin, D.; Manning, M.; Chen, Z.; Marquis, M.; Averyt, K.B.; Tignor, M.; and Miller, H.L.. ed. *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press

[7] (NOAA)2008 State of the Climate Report

[8] IPCC, 2007: Summary for Policymakers. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning,Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

frequency of extreme weather events; decreases in ice mass of glaciers, ice sheets and sea ice; ocean warming and acidification[9]; and alterations in ocean circulation patterns.

Figure 1.1 Annual land, annual ocean, and combined annual land-ocean global temperature anomalies for the past 130 years indicating a significant rise over the last 30 years. Land surface temperatures are generated from the Global Historical Climate Network-Monthly **(GHCN-M)**. Sea surface temperatures are determined using the Extended Reconstructed Sea Surface Temperature **(ERSST)** analysis[10].



The South Carolina Department of Natural Resources recognizes the need to address potential climate change as a threat-multiplier that could create new natural resource concerns, while exacerbating existing tensions already occurring as a result of population growth, habitat loss, environmental alterations and overuse. Climate-related changes may adversely affect the environment in many ways, potentially disrupting or damaging ecological services, water supply, agriculture and forestry, fish and wildlife species and their habitats, endangered species and commercial and recreational fishing. One particular impact is sea-level rise and its effects on coastal areas. Rising sea level may amplify problems of coastal flooding, coastal erosion, and general disruptions to sensitive coastal and estuarine ecosystems. Thoughtful and careful

[9] Effects of Climate Change and Ocean Acidification on Living Marine Resources, Written testimony presented to the U.S. Senate Committee on Commerce, Science and Transportation's Subcommittee on Oceans, Atmosphere, Fisheries, and Coast Guard, May 10, 2007

[10] http://www.ncdc.noaa.gov/cmb-faq/anomalies.php. Last accessed October, 2011

planning regarding climate change is needed in order to protect the valuable natural resources of the Palmetto State. In response to these challenges, DNR has prepared this report to address potential impacts of climate change on the natural resources of South Carolina and guide the agency's adaptive response strategy to offset, minimize, or delay these effects.

1.2 Background

South Carolina's natural resources contribute nearly $30 billion and 230,000 jobs to the state's economy. These economic benefits include forestry, mining, recreational fishing, hunting and wildlife viewing, a large part of the tourism market, and the recreational industry. South Carolina's beaches alone generate about $3.5 billion annually and support 81,000 jobs. Fishing, hunting and wildlife viewing contribute almost $2.2 billion annually to South Carolina's economy and support nearly 59,000 jobs, while the state's forestry industry exports more than $1 billion in forest products, supporting more than 83,000 jobs[11].

DNR is charged by law (Titles 48 and 50, South Carolina Code of Laws (1976), as amended) with the management, protection and enhancement of natural resources in South Carolina[12]. Additionally, DNR is charged with regulating watercraft operation and associated recreation, including establishing boating safety standards. Title 49, South Carolina Code of Laws, authorizes DNR as the state agency responsible for considering water supply (domestic, municipal, agricultural and industrial) issues, water quality facilities and controls, navigation facilities, hydroelectric power generation, outdoor recreation, fish and wildlife opportunities, and other water and land resource interests. This title also charges DNR with aquatic plant management, comprehensive drought planning, management and coordination of State Scenic Rivers and the conservation, protection, and use of floodplain lands.

DNR is the steward of the State's natural resources and is responsible for the protection and management of these resources for the use and enjoyment of the public. Natural resources within DNR's purview include land, water, mineral and biological resources. In carrying out its responsibilities, DNR must balance its objectives and actions holistically in order to most appropriately protect and sustain the natural resources of South Carolina.

DNR is a multifaceted agency consisting of the fish and wildlife sciences and the offices of the State Climatologist, State Geologist and State Hydrologist. Scientists in all divisions of the DNR are concerned over the potential impacts of climate change on natural resources. In fact, natural resource agencies across the nation, both state and federal, are examining climate change and the specific issues affecting their area of responsibility and core mission. DNR recognizes climate change as a real phenomenon, grounded in numerous scientific studies, and DNR recognizes that

[11] Underappreciated Assets: The Economic Impact of South Carolina's Natural Resources, University of South Carolina Moore School of Business, 2009, http://www.dnr.sc.gov/green/greenreport.pdf
[12] http://www.scstatehouse.gov/code/statmast.htm. Last accessed October 2011.

thoughtful and careful planning is needed in order to protect the natural resources of the Palmetto State to benefit its citizens in the future.

South Carolina state government has been involved in the climate change discussion primarily through the Climate, Energy and Commerce Advisory Committee called to action by former Governor Mark Sanford in 2007. The committee consisted of elected officials and leaders from government agencies, utilities, non-government organizations, businesses, and industry. The final committee report examined present and projected state contributions to GHG, and recommended ways to reduce GHG output over the next planning horizon, which was defined as by 2020 and beyond. Of particular note, the report recommended a comprehensive set of 51 specific policies to reduce GHG emissions and address climate-, energy-, and commerce-related issues in South Carolina[13]. The State has taken positive steps toward developing policies that will decrease the contribution of GHG emitted from Palmetto State sources, and the State has joined with states across the nation in an effort to mitigate the potential impacts of climate change by reducing the greenhouse effect [14].

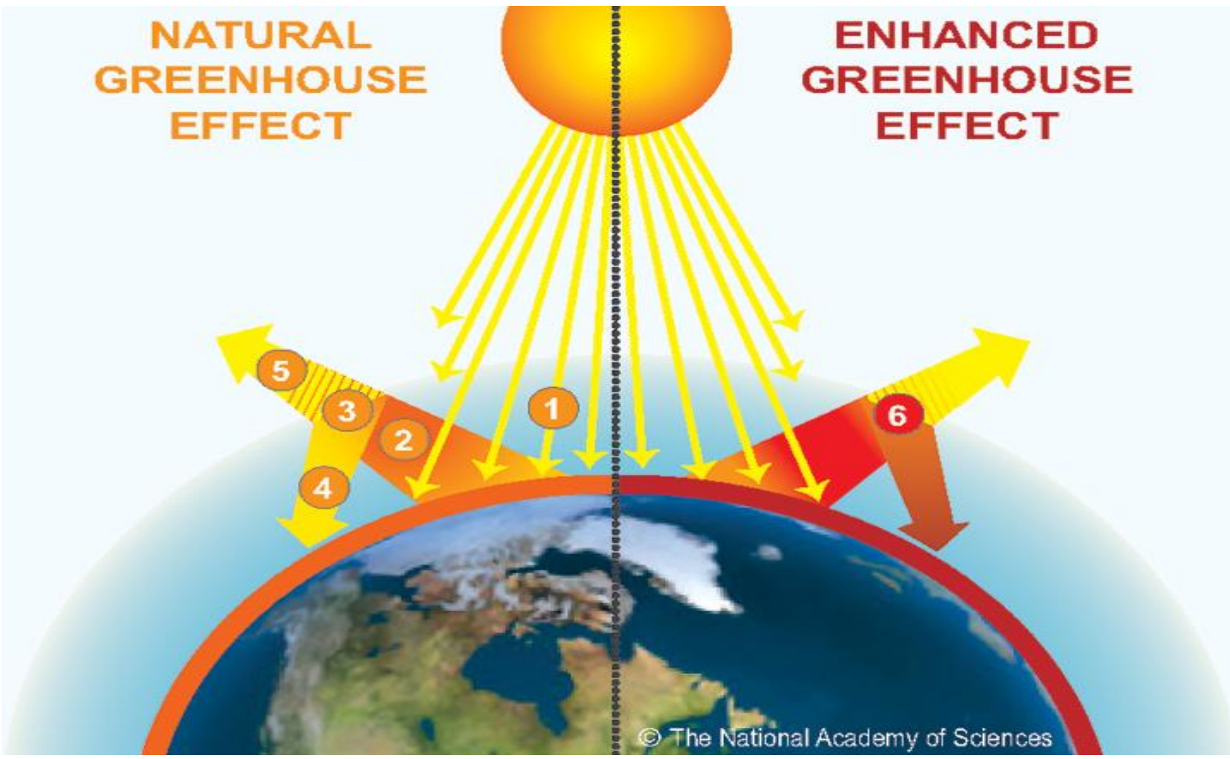
1.3 Greenhouse Effect

The greenhouse effect is a natural phenomenon that keeps the Earth insulated from the cold temperatures in space. Solar radiation enters the atmosphere and is absorbed and reemitted back from the Earth's surface as infrared energy. The greenhouse gases (GHGs) in the atmosphere prevent some of this heat energy from escaping back into space and reflect it back down to the surface. Since the industrial revolution, however, emissions of these gases have increased and accumulated. These larger volumes of atmospheric GHG are trapping more and more heat resulting in an enhanced greenhouse effect. The greenhouse effect is depicted in Figure 1.2.

There are ten primary GHGs, of which water vapor (H_2O) is the only GHG that is solely naturally occurring. Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are naturally occurring and also are created from anthropogenic sources[15]. After water vapor, carbon dioxide is the second most abundant greenhouse gas. It occurs naturally as part of the carbon cycle, which includes inputs from animal and plant respiration, ocean-atmosphere exchanges of gases, as well as outgassing from volcanic eruptions. It is also estimated to be responsible for 9–26 percent of the greenhouse effect[16]. Since the mid 18th century, anthropogenic activity has increased the concentration of carbon dioxide and other greenhouse gases (Figure 1.3). This has resulted in atmospheric concentrations of carbon dioxide being 100 ppm higher than pre-industrial levels[17].

[13] South Carolina Climate, Energy and Commerce Advisory Committee. 2008. Final Committee report. 653 pp. Hereinafter CECAC 2008. http://www.scclimatechange.us/index.cfm Last accessed October 2011.
[14] http://www.scclimatechange.us/ Last accessed Jan 2011.
[15] Center for Sustainable Systems, University of Michigan. 2010. "*U.S. Greenhouse Gases Factsheet.*" Pub. No. CSS05-21. http://css.snre.umich.edu/css_doc/CSS05-21.pdf. Last accessed October 2011.
[16] [4] Kiehl, J.T.; Trenberth, K.E. (1997). "Earth's Annual Global Mean Energy Budget" (PDF). *Bulletin of the American Meteorological Society* **78** (2): 197–208
[17] Climate Change 2001: Working Group I: The Scientific Basis: figure 6-6.

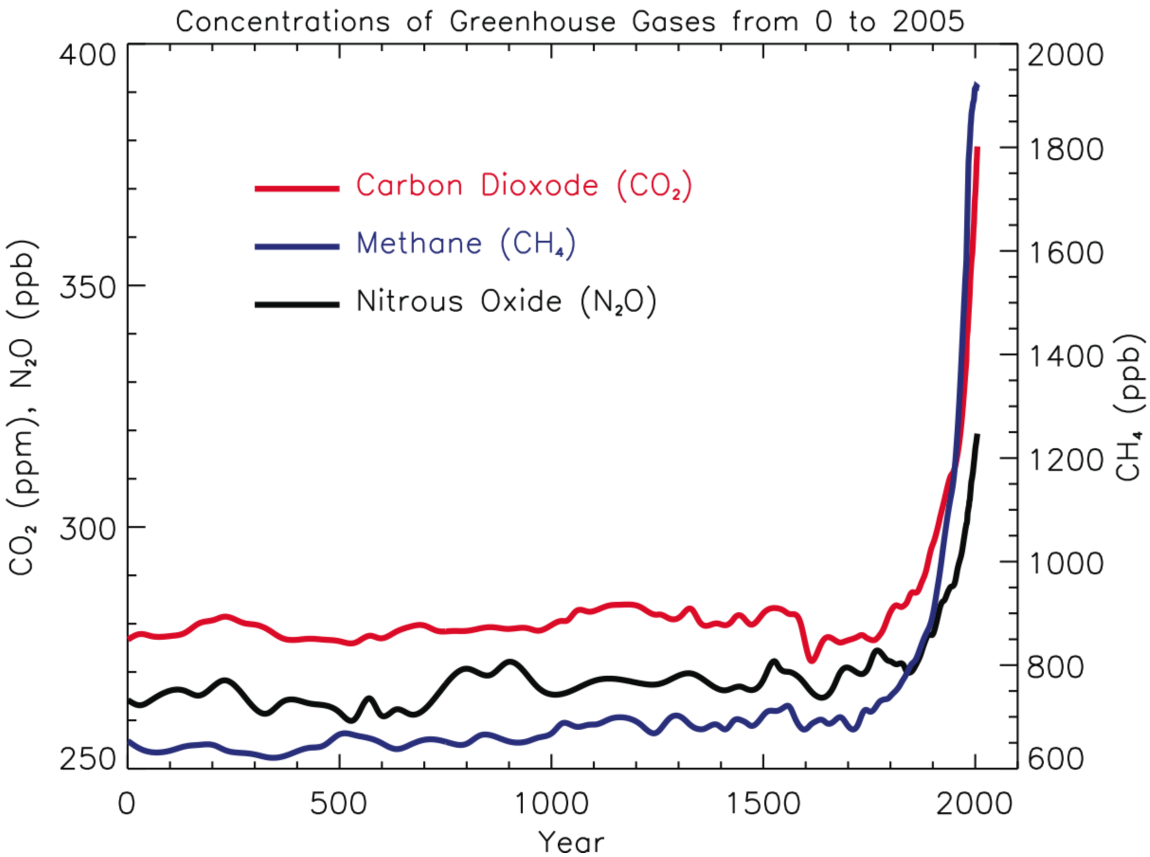
Figure 1.2 The greenhouse effect illustrated: visible sunlight passes through the atmosphere without being absorbed. Some of the sunlight striking the earth is (1) absorbed and converted to infrared radiation (heat), which warms the surface. The surface (2) emits infrared radiation to the atmosphere, where some of it (3) is absorbed by greenhouse gases and (4) re-emitted toward the surface; some of the infrared radiation is not trapped by greenhouse gases and (5) escapes into space. Human activities that emit additional greenhouse gases to the atmosphere (6) increase the amount of infrared radiation that gets absorbed before escaping to space, thus enhancing the greenhouse effect and amplifying the warming of the Earth[18].



Methane (CH_4) is the third most abundant greenhouse gas, and remains in the atmosphere for approximately 9-15 years. It is over 20 times more effective in trapping heat than carbon dioxide (CO_2) over a 100-year period[19]. It is formed from a variety of natural and anthropogenic processes. Methane occurs naturally when organic material decomposes. The main natural sources of methane are wetlands, termites, bodies of water, and gas hydrates. The major anthropogenic sources are landfills, natural gas and petroleum systems, agriculture, and coal mining.

[18] Reprinted by permission of the Marian Koshland Science Museum of the National Academy of Sciences, http://www.koshland-science-museum.org.
[19] http://www.epa.gov/methane/. Last accessed October 2011

Figure 1.3 This figure shows the concentrations of carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O) in the atmosphere from year 0 to 2005.



Source: National Center for Atmospheric Research (NCAR), WMO:Concentrations of greenhouse gases from 0 to 2005, http://gcmd.nasa.gov/records/GCMD_WMO_Concentrations_greenhouse_gases0-2005.html

Nitrous oxide (N_2O) is the fourth most abundant greenhouse gas. Despite its lower concentration, it is 310 times more powerful at trapping atmospheric heat than carbon dioxide, and remains in the atmosphere for 120 years[20]. It is naturally emitted from oceans and soils, but anthropogenic sources include agricultural (mostly nitrogen fertilization) and industrial activities, fossil fuel combustion, and nitric acid production.

Between 10,000 and 150 years ago, atmospheric concentrations of CO_2, CH_4, and N_2O were relatively stable. In the last 150 years, concentrations of CH_4 and N_2O increased 148% and 18%, respectively[21]. Table 1.1 compares the preindustrial and current levels of the primary anthropogenically-produced GHG and their radiative forcing. Radiative forcing is a measure of the influence an external factor has on the balance of incoming and outgoing energy and is an index of the importance of the factor as a potential

[20] http://www.epa.gov/nitrousoxide/. Last accessed October 2011
[21] IPCC (2007) *Climate Change 2007: The Physical Science Basis*. Intergovernmental Panel on Climate Change; Ed. S. Solomon et al.; Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

climate change mechanism. Radiative forcing values are for changes relative to preindustrial conditions in 1750 and are typically expressed in watts per square meter (W/m^2).

Table 1.1 Preindustrial and current levels of the primary anthropogenically-produced GHG and their radiative forcing.

Gas	Preindustrial level	Current level	Increase since 1750	Radiative forcing (W/m^2)
Carbon dioxide	280 ppm	388 ppm	108 ppm	1.46
Methane	700 ppb	1745 ppb	1045 ppb	0.48
Nitrous oxide	270 ppb	314 ppb	44 ppb	0.15

Source: http://en.wikipedia.org/wiki/Greenhouse_gas, Last Accessed

1.4 Climate

Climate is defined as the complex, interactive system consisting of the atmosphere, land surface, snow and ice, oceans and other bodies of water, flora and fauna. Climate can be described in terms of the average temperature, humidity, atmospheric pressure, precipitation, wind and other parameters over a period of time, ranging from months to millions of years. Modern climate studies tend to use intervals of 30 years to define climate norms. The climate of a location is affected by its latitude, terrain and altitude, as well as nearby water bodies and their currents[22]. The generalized worldwide climate classifications are depicted in Figure 1.4.

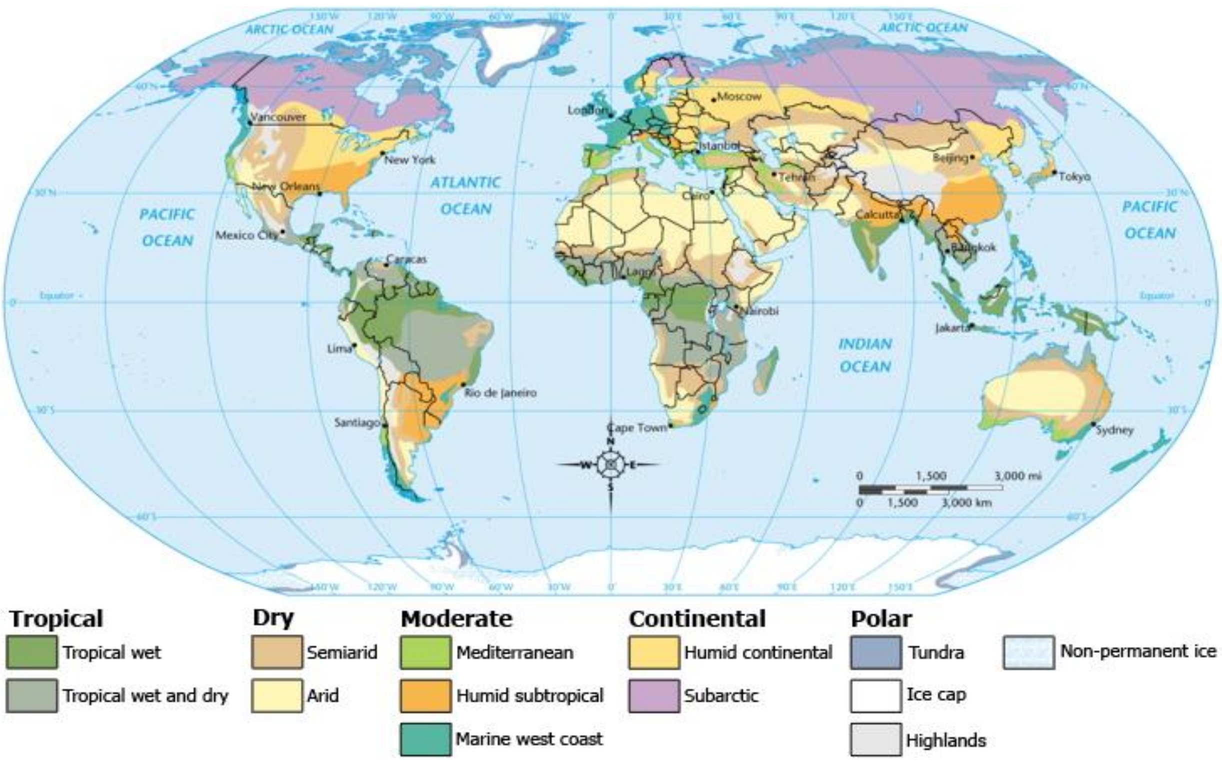
Climate has varied through time under the influence of its own internal dynamics involving changes such as volcanic eruptions and solar variations. Now, human-caused changes in atmospheric composition appear to be influencing climate change. Ultimately, the energy of the Sun drives the Earth's climate. Climate changes may occur in a limited number of ways including: (1) changes in incoming solar radiation resulting from changes in Earth's orbit or in the Sun itself, (2) changes in the fraction of solar radiation that is reflected back into space, otherwise known as albedo, and (3) changes in the amount of infrared radiation reflected back to to Earth by GHG concentrations. Although climate responds directly to these, it also can respond indirectly, through a variety of feedback mechanisms[23]. The climate system is

[22] Thornthwaite, C. W. 1931. The Climates of North America: According to a New Classification, Geo. Rev. 21(4):633-655.

[23] Le Treut, H., R. Somerville, U. Cubasch, Y. Ding, C. Mauritzen, A. Mokssit, T. Peterson and M. Prather, 2007: Historical overview of climate change. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, *eds*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

characterized by positive and negative feedback effects between processes that affect the state of the atmosphere, oceans and land. An example of a climate feedback mechanism is the ice-albedo positive feedback loop. Melting snow exposes more dark ground, with lower albedo, which in-turn absorbs heat that would have been reflected back into space by snow or ice[24].

Figure 1.4 Generalized worldwide climate classifications noting the southeastern United States to be part of the humid subtropics.



1.5 <u>Weather</u>

Weather occurs in the troposphere, or the lowest portion of the atmosphere. It is the current, localized condition of atmospheric elements.[25] Common weather factors that affect daily life include wind, clouds, rain, sleet, snow and fog. Less common weather events that occur in South Carolina and the southeastern United States are tornadoes and hurricanes. These natural disasters cause economic distress as well as loss of property and life.

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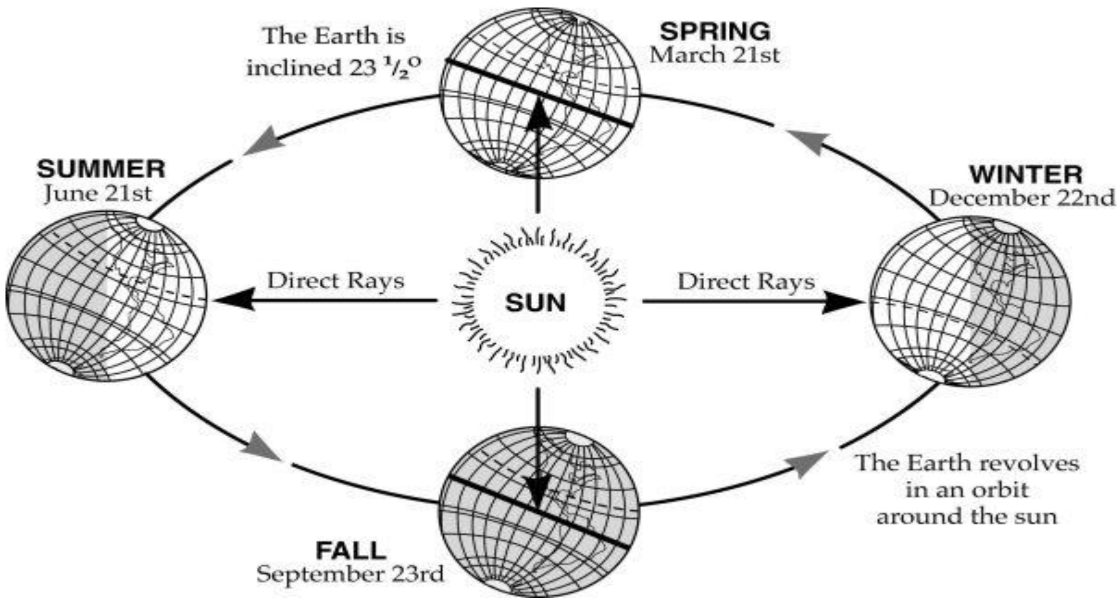
[24] Heimann, M. and M. Reischstein. 2008. Terrestrial ecosystem carbon dynamics and climate feedbacks. Nature. 451(289-292).
[25] Karl, T. R., J. M. Melillo and T. C. Peterson, eds. 2009. Global Climate Change Impacts in the United States. Cambridge University Press.

The Earth rotates daily on its axis, and its axis precesses, or wobbles, over the course of a year (Fig 1.5). Thus, the incident angle of solar insolation on a seasonal basis. Weather results from many factors, but the primary cause is differential heating of the Earth rotating on a variable axis and orbiting around the sun. This differential heating varies by time and location and is complicated by topography and bathymetry resulting in variability in temperature, moisture distribution and atmospheric dynamics. Figure 1.5 depicts the Earth's orbit around the Sun and the relative inclination of the Earth to the Sun.

Figure 1.5 The Earth orbits around the Sun. As the Earth moves around the Sun it is tilted 23.5° from the perpendicular. The Earth's revolution and inclination cause the changing seasons. The arrows extending from the Sun to the Earth represent where the direct rays of the Sun strike the Earth on the first day of each season.[26]



1.6 Methodology

Although temperature at the surface of the Earth is typically used as a primary indicator of climate change, there are other key measures that should be considered. Some of the other key measures and datasets include air temperature observed above both the land and sea, water temperature at the sea-surface extending hundreds of meters below the surface, changes in humidity, changes in sea level, and changes in sea-ice, glaciers and snow cover[27].

[26] © Herff Jones, Inc. Used by permission. All rights reserved.
[27] Evidence: The state of the climate, Met Office, UK, 2010 http://www.metoffice.gov.uk/media/pdf/m/6/evidence.pdf Last accessed Oct. 2011

1.6.1 Satellite versus Surface Observations

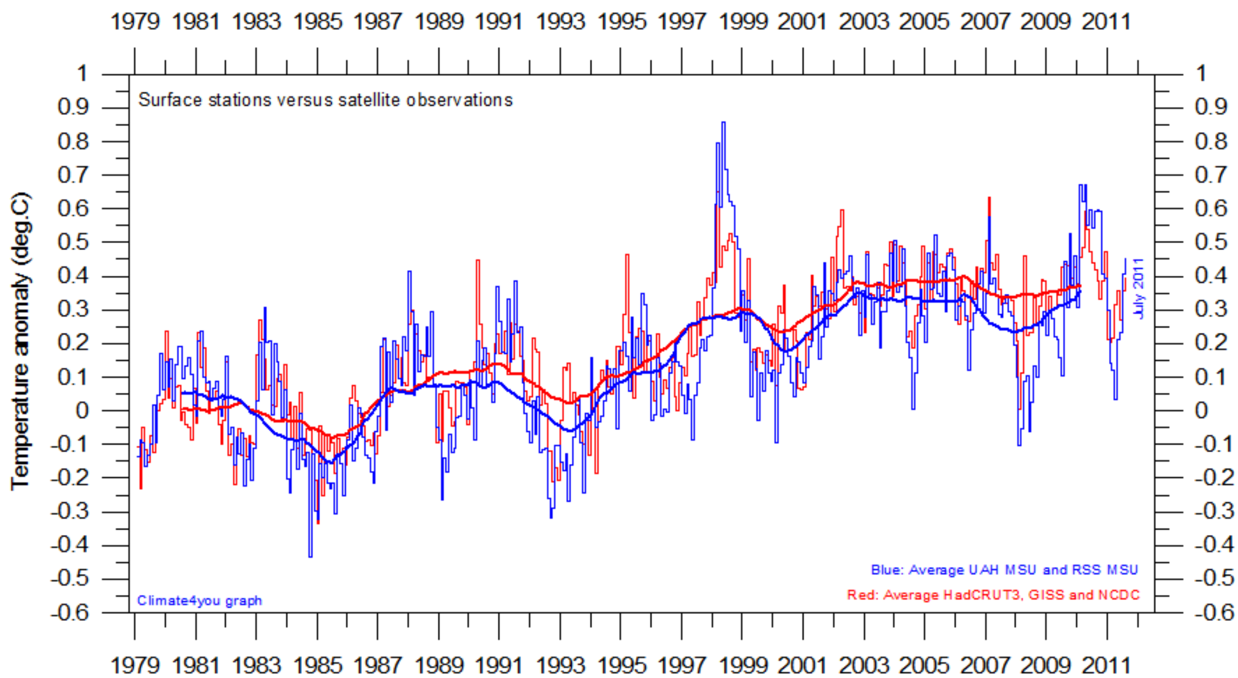
Deriving reliable global temperature from instrument data is a difficult task because the instruments are not evenly distributed across the planet, the hardware and locations have changed over time, and there has been extensive land use change around some of the sites. There are three main datasets showing analyses of surface global temperatures; the joint Hadley Centre/University of East Anglia Climatic Research Unit temperature analysis (HadCRUT), Goddard Institute for Space Studies (GISS), and the National Climatic Data Center (NCDC). These datasets are updated on a monthly basis and are generally in close agreement.

Since the satellite era took off in the late 1970s, both atmospheric and surface temperatures were able to be determined using satellite measurements. Satellites do not measure temperature directly, but instead measure how much light is emitted or reflected in different wavelength bands. Using mathematical calculations, temperature time series are indirectly inferred and reconstructed. This is advantageous over other methods because it provides global coverage. Because of slight differences in methodology, satellite-derived temperature datasets often differ. Thus it is imperative to make routine corrections due to orbital drift or decay, and sensor deterioration.

Two satellite datasets, the Remote Sensing Systems (RSS) dataset and the one prepared by the University of Alabama in Huntsville (UAH), utilize Microwave Sounding Units (MSU) of orbiting satellites to estimate lower tropospheric temperature. This is done by measuring microwave emissions of oxygen molecules, which increase proportionally to temperature. Lower tropospheric temperatures are expected to be slightly higher than surface temperatures, so the surface temperature record produced using these measurements is adjusted accordingly. Temperature measurements based on MSU also provide sparse coverage of Arctic and Antarctic regions. Figure 1.6 indicates that the average surface-based temperatures are slightly different to those obtained by satellites. Although the general agreement is good, satellites seem to record a larger temperature variability than surface observations. Additionally, over the entire time period shown in this plot, the average of the surface-based estimates suggests a less than 0.1^{o}C larger global temperature increase, compared to the average of satellite-based observations. The surface temperature record has increased at approximately 0.17 °C/decade since 1979. Comparing these values to satellite temperature estimates through January 2011, RSS shows an increase of 0.148 °C/decade while UAH finds an increase of 0.140°C/decade.[28]

[28] Remote Sensing Systems". http://www.ssmi.com/msu/msu_data_description.html. Retrieved 2009-01-13. "UAH". http://vortex.nsstc.uah.edu/data/msu/t2lt/tltglhmam_5.4. Retrieved 2011-01-14.

Figure 1.6 Average monthly global surface air temperature estimates (HadCRUT3, GISS and NCDC) and satellite-based temperature estimates (RSS MSU and UAH MSU). The thin lines indicate the monthly value and the thick lines represent the simple running 37 month average, nearly corresponding to a running 3 year average.



1.6.2. Climate Models and Projections

Climate models are based on computer programs that contain various mathematical equations. These equations quantitatively describe how atmospheric variables such as temperature, air pressure, wind, greenhouse gases and precipitation respond to incoming and outgoing solar radiation. Climate models are used for a variety of purposes from the study of climate system dynamics to future climate predictions. Predicting temperature changes caused by increases in atmospheric concentrations of greenhouse gases is one of the better known applications of climate modeling.

The Intergovernmental Panel on Climate Change (IPCC) is currently the leading international organization for the assessment of climate change. It was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO). The IPCC is a scientific body that reviews the most recent scientific, technical, and socio-economic information produced worldwide. Although the IPCC does not conduct any original research or monitor climate data, its membership consists of the leading researchers and scientists in climate studies.

The IPCC delivered assessment reports in 1990, 1995, 2001, and 2007. Within these reports are model-derived estimates of future climate (i.e. projections). Some of these climate projections are based on scenarios that assume different levels of future CO_2 emissions. Each scenario has a range of possible outcomes associated with it. The most optimistic outcome assumes an aggressive campaign to reduce CO_2 emissions; the most pessimistic is a "business as usual" scenario, while other scenarios fall in between. In the Fourth Assessment Report published in 2007, some of the projections state that global temperatures could rise between 1.1 and 6.4 °C (2.0 and 11.5 °F) during this century and that sea levels could rise by 18 to 59 centimeters (7.1–23 in).

1.7 Climate Change Adaptation and Mitigation

The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as:

> *The adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.*[29]

Adaptation may be more simply defined as *coping*. Climate scientists agree that climate change will occur in the future, even if the rates of GHG emissions decline. Adapting to climate change will therefore become necessary in certain regions in order to protect or sustain certain environmental systems, species and habitats. The need for adaptation may be increased by growing populations in areas vulnerable to extreme events. However, according to the IPCC:

> *Adaptation alone is not expected to cope with all the projected effects of climate change, and especially not over the long term as most impacts increase in magnitude*.[30]

Mitigation for climate change will involve changes in environmental and industrial behavior and practices such as reducing the rates of GHG emissions and increasing the rates of GHG sequestration. Decreasing consumption of fossil fuels is the best way to reduce GHG emissions, although these may be reduced by other ways such as conservation and recycling practices and utilizing alternative forms of energy. One of the best ways to sequester CO_2 is to protect acreage and growing timber – this is a natural fit for DNR's overall mission and is in keeping with DNR objectives to make land available to the using public.

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[29] Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[30] Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate ChangeCore Writing Team, Pachauri, R.K. and Reisinger, A. (Eds.) IPCC, Geneva, Switzerland. pp 104

1.8 DNR Climate Change Mission Statement

DNR's mission in response to the potential challenges of climate change to South Carolina is two-fold:

1. Identify issues and assess potential impacts of climate change on the natural resources of South Carolina, and
2. Develop an adaptive response strategy in order to offset, minimize, or delay the effects of climate change on natural resources.

The potential issues and impacts of climate change on people, landscapes, ecosystems, and other features will vary. Understanding these potential impacts and issues will play a significant role in adaptation planning by the agency, and it will provide a foundation for leaders to make informed and effective decisions. At a time when funding for climate change adaptation is scarce, understanding the potential consequences associated with climate change is vital. Table 1.2 provides a generalized summary of potential climate change phenomena.

Table 1.2 Generalized summary of potential climate change impacts and consequences.[31] While some impacts and consequences may not directly affect South Carolina, all are expected to create indirect effects.

Climate Change Phenomena	Potential Impacts	Potential Consequences
• Increasing land, surface water, sea surface and atmospheric temperatures • Rising sea level	• More frost-free days/year • More heat waves • Changes in precipitation cycles • More frequent and prolonged droughts • Increased evapotranspiration • Increased frequency of wildfire • More severe flood events • More problems with invasive species • Spatial changes in species' ranges • Changes in timing of ecological events such as animal migration • Intra- and inter-specific competition for available resources as food chains are altered • Loss of sea ice, glacial coverage and polar snowpack • Increased coastal flooding • Increased coastal erosion • Rising water tables • Saltwater intrusion • Increased nonpoint source pollution • Increases in toxic substances flowing from upstream to coastal areas • Increases in numbers of threatened and endangered species • Decline in forest growth	• Widespread human health impacts • Changes in ecosystem services such as the ability of streams and wetlands to naturally filter, assimilate and degrade pollution • Decline in water quality and quantity • Surface and sea-water pH changes • Decline in productivity and availability of fish and other aquatic species although some species could benefit • Economic losses directed toward business associated with natural resource management in both inland as well as coastal zones • Loss of beaches • Increased storm surge flooding • Impacts to coastal infrastructure • Salt marsh conversion to open water • Freshwater marsh conversion to salt marsh • Loss of important recreational and commercial fishing and shell fishing habitats • Loss of coastal forest habitats • Loss of cultural resources • Extinction of threatened and endangered species

[31] National Oceanic and Atmospheric Administration NOAA. 2010. Adapting to Climate Change: A Planning Guide for State Coastal Managers. NOAA Office of Ocean and Coastal Resource Management. Hereinafter NOAA 2010. http://coastalmanagement.noaa.gov/climate/adaptation.html. Last accessed Sept 2010

1.9 Agency Goals to Address a Changing Climate

In response to the DNR Climate Change Mission Statement the agency will have the following goals:

1. Gather factual, accurate information and data on how climate change may affect wildlife, fisheries, water supply and other natural resources within South Carolina,
2. Identify monitoring and data needs required to assess impacts of climate change in the state,
3. Use factual information, data, research and modeling to determine what actions need to be taken to address climate change,
4. Ensure data quality, provide original research that addresses information needs and validate modeling results with collected data,
5. Identify opportunities to partner with other state agencies, academic institutions and non-profit organizations where needed to accomplish the mission,
6. Identify ways for state officials, local government and citizens to assist in mitigation of or adaptation to natural resource impacts related to climate change, and
7. Locate and obtain available funding to assist in meeting agency mission and goals related to climate change.

1.10 DNR Resource Divisions, Organization and Responsibility

1.10.1 Land, Water and Conservation Division

The DNR Land, Water and Conservation Division (LWC) develops and implements programs that study, manage and conserve land and water resources. This is accomplished by providing guidance in resource development and management through planning, research, technical assistance, public education and development of a comprehensive natural resources database. The scope of the division is broad and incorporates expertise in climatology, flood-plain mapping, geology, hydrology, land use, rivers and water conservation.

1.10.2 Marine Resources Division

The Marine Resources Division (MRD) is responsible for the management and conservation of the state's marine and estuarine resources. It also works with regional authorities such as the Atlantic States Marine Fisheries Commission (ASMFC) and the South Atlantic Fishery Management Council (SAFMC) to ensure that marine resources are sustainably managed throughout their range. MRD has 3 main sections with the following responsibilities:

1. The Office of Fisheries Management (OFM) reviews coastal development activities, recommends marine fishing seasons and fish size/creel limits,

issues permits and conditions for the harvest of marine species (e.g. fish, shrimp, crabs and oysters) and tracks trends in the harvest of marine species.

2. The Marine Resources Research Institute (MRRI) conducts research and long-term surveys of inshore and offshore resources (e.g., finfish, shellfish and marine habitats), assesses the effects of human activities on coastal resources, and operates marine stocking research programs (e.g., red drum and striped bass).
3. Coastal Reserves & Outreach (CRO) is responsible for MRD functions relating to coastal land management, education and outreach, and all programs in the ACE Basin National Estuarine Research Reserve[32] (1 of 28 reserves in the National Estuarine Research Reserves System).[33]

Data from numerous MRD programs indicate that the physical and biological systems of the coastal zone have already been impacted by increasing population density and development. Additional pressure on these systems from climate change is likely to exacerbate system degradation, although the extent of future degradation related to climate change is uncertain.[34] Ecological, social, educational and technological issues associated with climate change impacts in the marine environment are reviewed in this report.

1.10.3 Wildlife and Freshwater Fisheries Division

The Wildlife and Freshwater Fisheries (WFF) Division of DNR develops and implements programs that manage and conserve the wildlife and freshwater fishery resources of the state. The Wildlife Section protects, manages and enhances the state's habitats and associated wildlife for the public benefit of present and future generations. The Wildlife Section also is responsible for the state's Endangered Species Program which protects and enhances a variety of declining species and diminishing habitats. The Freshwater Fisheries Section provides protection, enhancement, and conservation of South Carolina inland aquatic resources. It also provides recreational fishing opportunities for the state's citizens through its operation of hatcheries, regional fisheries management, state public fishing lakes, research and diadromous fisheries coordination.

Pressures from increasing development, habitat loss and increasing numbers of invasive species have changed the landscape of South Carolina, negatively affecting wildlife and fish resources.[35] Climate change will exacerbate the effects of these pressures. Given the potential for severe impacts to our natural resources, it is critical

[32] http://www.nerrs.noaa.gov/Doc/SiteProfile/ACEBasin/html/resource/protland/lunerr.htm. Last accessed Dec 2010.

[33] http://www.chbr.noaa.gov/ecosystems/nerrs.aspx. Last accessed Oct 2011.

[34] NOAA. 2000. The potential consequences of climate variability and change on coastal areas and marine resources: Report of the Coastal Areas and Marine Resources Sector Team U.S. National Assessment of the Potential Consequences of Climate Variability and Change U.S. Global Change Research Program. D. F. Boesch, J.C. Field and D. Scavia, *eds*. NOAA Coastal Analysis Prog. Decision Analysis Series No. 21. 181 pp. http://www.cop.noaa.gov/pubs/das/das21.pdf. Last accessed Dec 2010.

[35] Environmental Law Institute. 2002. Mitigation of impact to fish and wildlife habitat: Estimating costs and identifying opportunities. http://www.elistore.org/Data/products/d17_16.pdf. Last accessed Oct 2011.

to plan ahead to address the effects of climate change on our native wildlife and fish species and essential habitats.

2.0 THE CLIMATE OF SOUTH CAROLINA – PAST AND PRESENT

2.1 Paleoclimatology: Recent Studies and Contributions to Climate Modeling

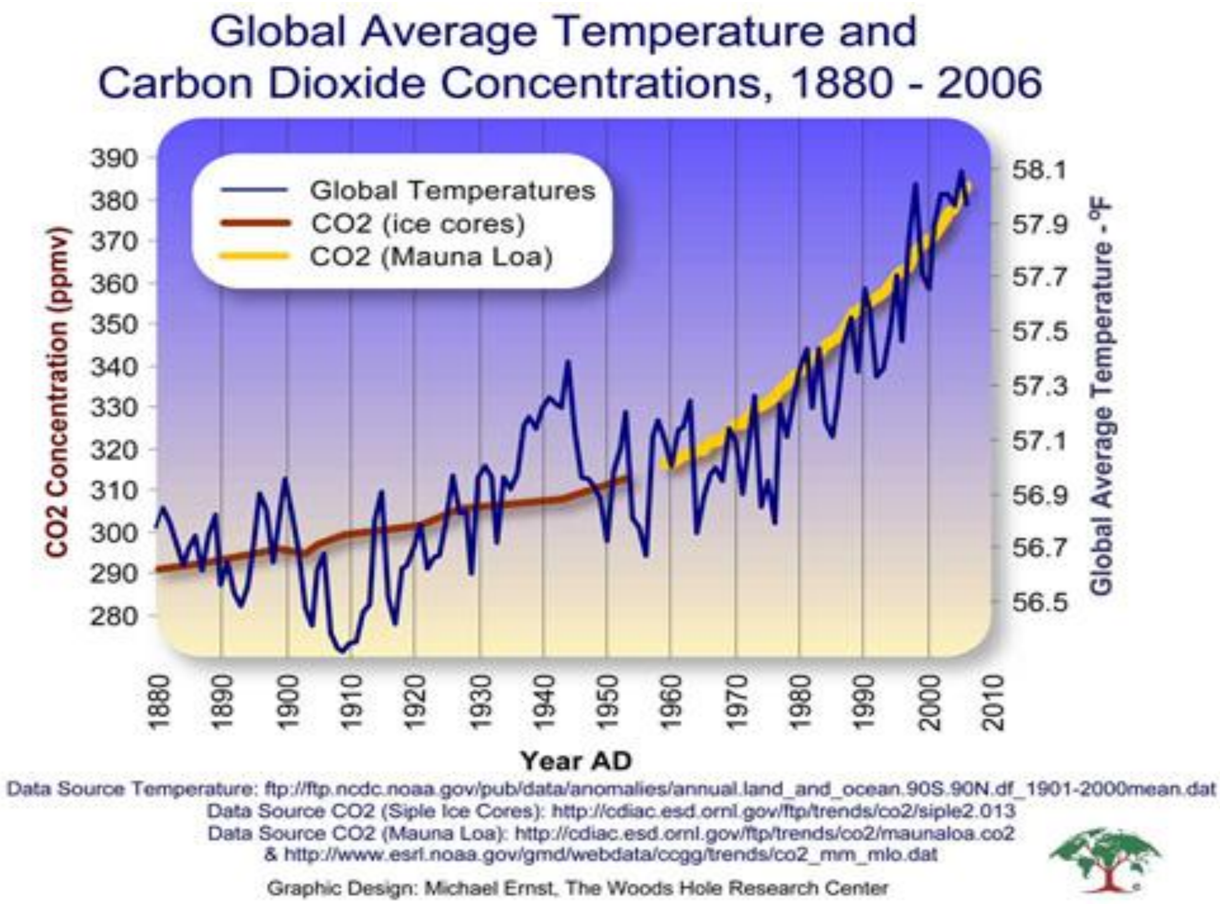
Climatology is the study and analysis of weather records over an extended period of time. Instruments such as thermometers and rain gauges have evolved since the 1700s and are now routinely used to record weather conditions. To reconstruct climate from an earlier time, it is necessary to use natural climate recorders, such as ice cores, tree rings, ocean and lake sediments, and corals. Measurements collected from these natural climate archives are called proxies because they do not provide a direct measurement of climate, as an instrument does. Rather, scientists deduce past climatic conditions from the physical and biological parameters contained in the proxy. The study of climate prior to the use of instrumental records is known as paleoclimatology.

Climatic conditions preserved in various proxies provide a way of understanding past changes in the environment where the proxy grew or existed. The ring width of a tree is an example of a proxy for temperature, or in some cases rainfall, because the thickness of the annual ring is sensitive to the temperature and rainfall of that year. The greatest understanding of paleoclimate comes when there are multiple data sets, providing a robust view of conditions. Figure 2.1 illustrates a reconstruction of global average temperature and CO_2 concentrations using both proxy measures of CO_2 from the Vostok ice core and instrumental CO_2 records from Mauna Loa Observatory in Hawaii.

Paleoclimate studies indicate that the earth's climate has changed many times throughout its history, and cycles of climate change have been recognized on a variety of time scales. Results from paleoclimate studies include the identification of regular episodic changes and the concept of abrupt climate change. The first is the result of a robust and expanding paleoclimate database. The second result owes, in part, to the greater precision of the datasets that have revealed dramatic climate shifts occurring in very short time spans.[36]

[36] NANRC 2001.

Figure 2.1 Global Temperature and CO_2 Concentration Since 1880. Data from NOAA's National Climate Data Center (NCDC) & Oak Ridge National Laboratory.[37]



2.2 Results of Studies

Paleoclimatic records are more precise and accurate in the last million years, and the last 650,000 years have been extensively studied because of well-preserved glacial and geological records. Currently, we are in an interglacial, or warm, period, which began at the end of the last glacial maximum (LGM) 13,500 years ago. The identification of episodic climates shows that glacial-interglacial, or cooling-warming, cycles can be recognized in the last million years, and that recurring intervals can be recognized. A well-supported theory suggests that these intervals correspond to Earth's orbital deviations. The relationship between orbital variations and glacial periods is referred to as a Milankovitch cycle. Although the Milankovitch Theory accounts for many glacial periods, some periods still defy a solely celestial cause.

[37] Data from NOAA's National Climate Data Center (NCDC) and Oak Ridge National Laboratory. http://www.whrc.org/resources/primer_fundamentals.html last accessed July 2010.

Much research has focused on the last 13,500 years, since the end of the last glacial period, and particularly on the last 2,000 years. The last 2,000 years are of interest because interglacial conditions were relatively stable, and thus provide a baseline to study modern climate variations. Three significant periods of climate variation, however, have occurred since the end of the LGM. In the upper latitudes of the Northern Hemisphere 12,800-11,500 years ago, oxygen-isotope-derived temperatures from an ice core in Greenland indicate conditions approximately 45-59°F (7-15°C) colder than present-day Greenland. This late Pleistocene glacial stadial event, or cooler period, is referred to as the Younger Dryas. The end of the Younger Dryas was marked by rapid transition from stadial to interglacial conditions and occurred in a time span of 20 years, possibly even less. The Medieval Warm Period occurred between 800-1300 AD and is primarily documented in Europe. It is recognized as an interglacial period bracketed by older and younger stadial events, so the description of warm is relative. Another stadial event in more recent times is also of interest. The Little Ice Age occurred from the 16th until the mid-19th centuries and affected the Northern Hemisphere, although in lesser magnitude than the Younger Dryas. There are numerous historical records documenting the shifts which occurred during the Little Ice Age.[38]

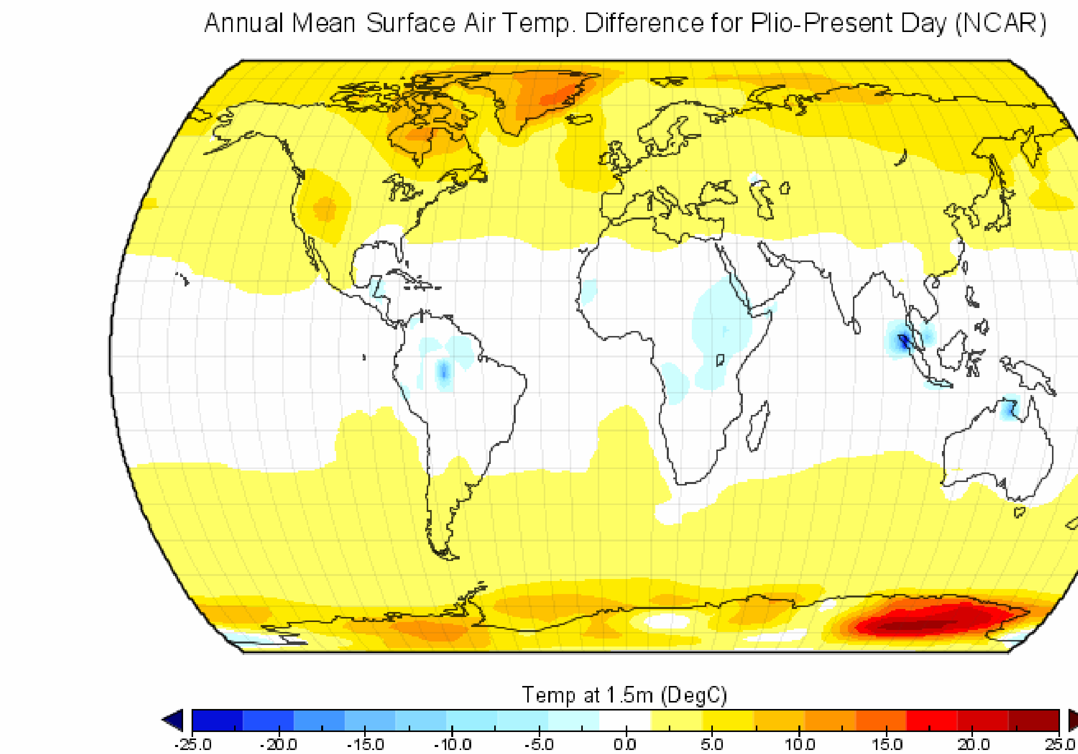
The recognition of a mid-Pliocene warm period (Fig 2.2), approximately 3.3 to 3.0 million years ago, may provide insight into what could happen during the present period of climate change. The mid-Pliocene change happened recently enough that the configuration of continents and oceans has not changed significantly, and air and ocean currents probably were similar to those of today. Mean-global temperatures during the mid-Pliocene warm period were 2-3°C above pre-industrial-age temperatures. CO_2 levels were in the range of 360-400 ppm, and the extent of ice sheets was reduced compared to today. These conditions resulted in sea level being 15-20 meters above present-day levels, and there was lower continental aridity.

The second major result of paleoclimate studies is the recognition of abrupt shifts in climatic conditions. Some of these shifts involved extreme changes in conditions, such as large magnitude warming events with increases of up to 61°F (16°C). The time scale of some shifts is as little as 10 years. The causes of rapid climate shifts are not fully understood, but it is thought they result from a combination of several natural processes.[39] The question now is whether human inputs of GHGs, along with trends in natural processes, trigger an abrupt climate change. If an abrupt shift in climate is possible, prudent planning necessitates efforts to predict both the magnitude and duration of the change.

[38] Jansen, E., J. Overpeck, K.R. Briffa, J.-C. Duplessy, F. Joos, V. Masson-Delmotte, D. Olago, B. Otto-Bliesner, W.R. Peltier, S. Rahmstorf, R. Ramesh, D. Raynaud, D. Rind, O. Solomina, R. Villalba and D. Zhang, 2007: Palaeoclimate. *in* Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, *eds.* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 66 pp.

[39] NANRC 2001.

Figure 2.2 Annual Mean Surface Air Temperature Difference between Pliocene and Present Day. Global temperatures, particularly at high latitudes, are believed to have been significantly warmer than today.[40]



2.3 Paleoclimate Summary and Recommendations for the Future

Paleoclimate studies indicate that climate variation is a natural phenomenon. The focus of paleoclimate studies is shifting now toward identifying the processes and causes of climate change. To date, no systematic study of South Carolina's paleoclimate has been done. Some studies have addressed climatic conditions at a specific time or at a specific site, but no studies have been done to document the state's climate over an extended period of time. The state's paleoclimate record should be studied at several time scales. First, the climate since European settlement should be reconstructed by examining local and state records, which would provide a detailed account of climate over the last 400 years. Instrument records can be integrated into this history. In addition to shorter term studies, studies extending back several thousand to several hundred thousand years could be useful.

[40] http://geology.er.usgs.gov/eespteam/prism/products/agu3.pdf

2.4 South Carolina Climate in the Early 21st Century[41]

South Carolina's location provides a mild climate and, in normal years, generous rainfall. Several factors responsible for this include our relatively low latitudinal location and a strong moderating influence from Atlantic Ocean warm water. Also of importance are the Blue Ridge Mountains to the north and west, which help block or delay movement of cold air masses from the northwest.

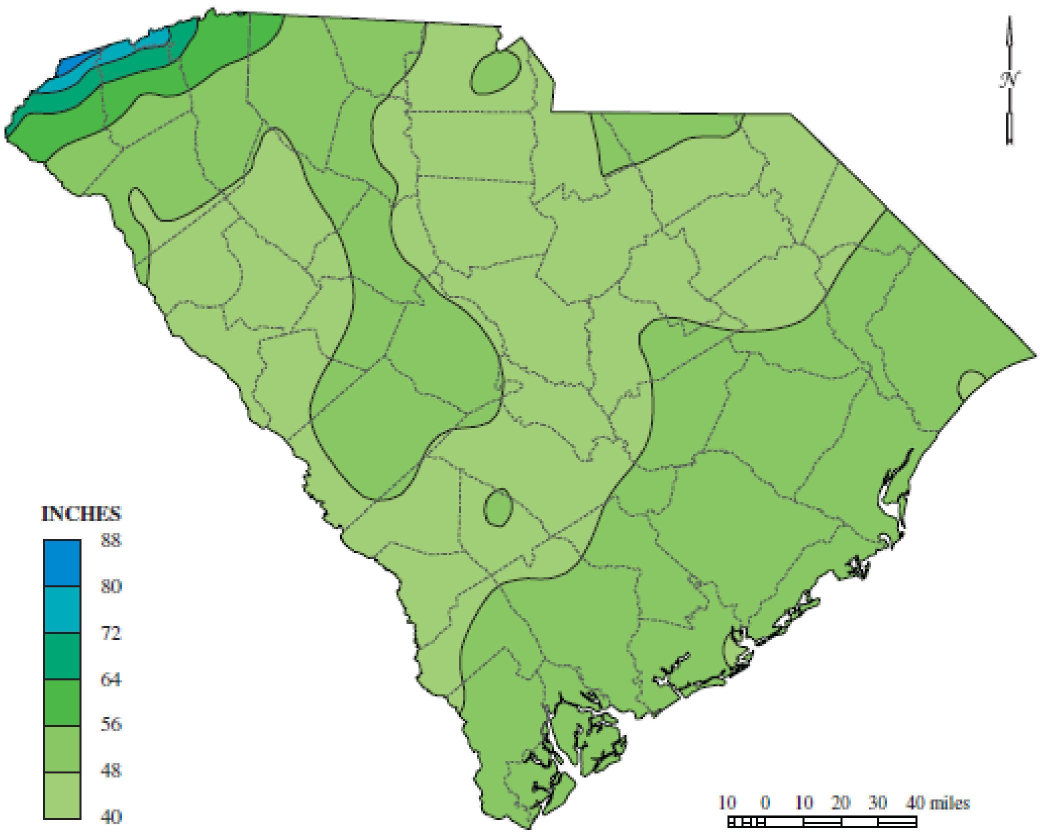
2.4.1 Precipitation

Precipitation in South Carolina is ample and distributed with two maxima and two minima throughout the year. The maxima occur during March and July; the minima occur during May and November. There is no wet or dry season; only relatively heavy precipitation periods or light precipitation periods. No month of the year averages less than 2 inches (5 cm) of precipitation anywhere in South Carolina. In the northwestern corner of the state, winter precipitation is greater than in summer and the reverse is true for the remainder.

The South Carolina average annual precipitation is slightly more than 48 inches (122 cm). Average annual precipitation is heaviest in the northwestern counties because moist air is forced up the mountains to higher and cooler elevations, where condensation and precipitation are initiated. In the Blue Ridge Mountains, 70-80 inches (179-203 cm) of rainfall occur on average at the highest elevations (Fig. 2.3), with the highest annual average of 79.29 inches (201.40 cm) occurring at Caesars Head. Across the foothills, average annual precipitation ranges from 60 inches (152 cm) to more than 70 inches (179 cm). In the eastern and southern portions of the Piedmont, the average annual rainfall ranges from 45-50 inches (114-127 cm). Areas in the northern Midlands report the lowest rainfall on average, between 42-47 inches (107-119 cm). Precipitation amounts are a little higher across the Coastal Plain. A secondary statewide maximum occurs parallel to the coast 10-20 miles (16-32 km) inland. This maximum, 50-52 inches (127-132 cm) is a result of the diurnal sea-breeze front thunderstorms prevalent during summer.

[41] http://www.dnr.sc.gov/climate/sco/ClimateData/cli_sc_climate.php. Last accessed May 2011.

Figure 2.3 South Carolina average annual precipitation, 1971-2000.



There is little difference in monthly rainfall distribution for the months of December-March, with the exception that the monthly total for March is somewhat higher than for any of the previous three months. During March, rainfall along the coast begins to increase, and by May the normal for the southern coast exceeds 5 inches (13 cm). At the same time, the central part of South Carolina receives only about 3 inches (8 cm) of rain and the mountains more than 5 inches (13 cm). During the summer, our weather is dominated by a maritime tropical air mass known as the Bermuda high, which forces warm, moist air inland from the ocean. As the air comes inland, it rises and forms localized thunderstorms, resulting in a precipitation maximum. Summer rainfall (June – August) is heaviest in the mountains, with 4-7 inches (10-18 cm) monthly, and along the coast with 6-8 inches (15-20 cm) monthly. During September, the greatest rainfall on average occurs along the coast. This is due to the passage of tropical storms and hurricanes that may influence coastal weather at this time of year. During October-November precipitation on average is at a minimum throughout the state. Any heavy precipitation during this period is likely to be the result of a hurricane or early winter storm. The greatest documented 24-hour rainfall was 14.80 inches (35.56 cm) observed at Myrtle Beach on September 16, 1999. The greatest total annual precipitation occurred in 1979 at Hogback Mountain in Greenville County, where more than 120 inches (305 cm) was recorded.

Wintry precipitation, such as snow, sleet and freezing rain, also affect South Carolina. Snow and sleet may occur separately, together, or mixed with rain during the winter months from November-March, although snow has occurred as late as May in the mountains. Measurable snowfall may occur from 1-3 times in a winter in all areas except the Lowcountry, where snowfall occurs on average once every 3 years. Accumulations seldom remain very long on the ground except in the mountains.

Typically, snowfall occurs when a mid-latitude cyclone moves northeastward along or just off the coast. The greatest snowfall in a 24-hour period was 24 inches (61 cm) at Rimini in February 1973. During December 1989, Charleston experienced its first white Christmas on record, and other coastal locations had more than 6 inches (15 cm) of snow on the ground for several days following. Episodes of sleet and freezing rain are observed statewide, although less frequently in the Lowcountry. One of the most severe cases of ice accumulation from freezing rain took place in February 1969 in several Piedmont and Midlands counties with significant timber losses and power disruptions.

Abnormal weather patterns can alter or restrict precipitation, resulting in prolonged dry spells. Periods of dry weather have occurred in each decade since 1818 (National Water Summary 1988-1989 Hydrologic Events and Floods and Droughts, 1991). The earliest records of drought indicate that some streams in South Carolina went dry in 1818, and fish in smaller streams died from lack of water in 1848. The most damaging droughts in recent history occurred in 1954[42], 1986[44], 1998-2002[43], and 2007-2008.[44] Severe droughts occur about once every 15 years, with less severe widespread droughts about once every 7 years. In 1954, the beginning of one of South Carolina's record droughts, only 20.73 inches (52.65 cm) of precipitation fell at Rimini, in Clarendon County, to set the record annual low precipitation value for the State.

2.4.2 Temperature

The state's annual average temperature is about 61°F (16°C). Local averages range from 55°F (12°C) at Caesars Head in the mountains to 66°F (19°C) along the southern coast at Beaufort (Fig 2.3). Elevation, latitude and distance from the coast are the main influences on temperature. The state's record low of -19°F (-28°C) was recorded at Caesars Head on January 21, 1985. Along the coast, ocean water temperatures vary a very small amount daily and annually when compared with adjacent land areas. The air

[42] National Water Summary 1988-1989 - Hydrologic Events and Floods and Droughts (1991), 2375, United States Geological Survey, United States Government Printing Office, Denver, Colorado.

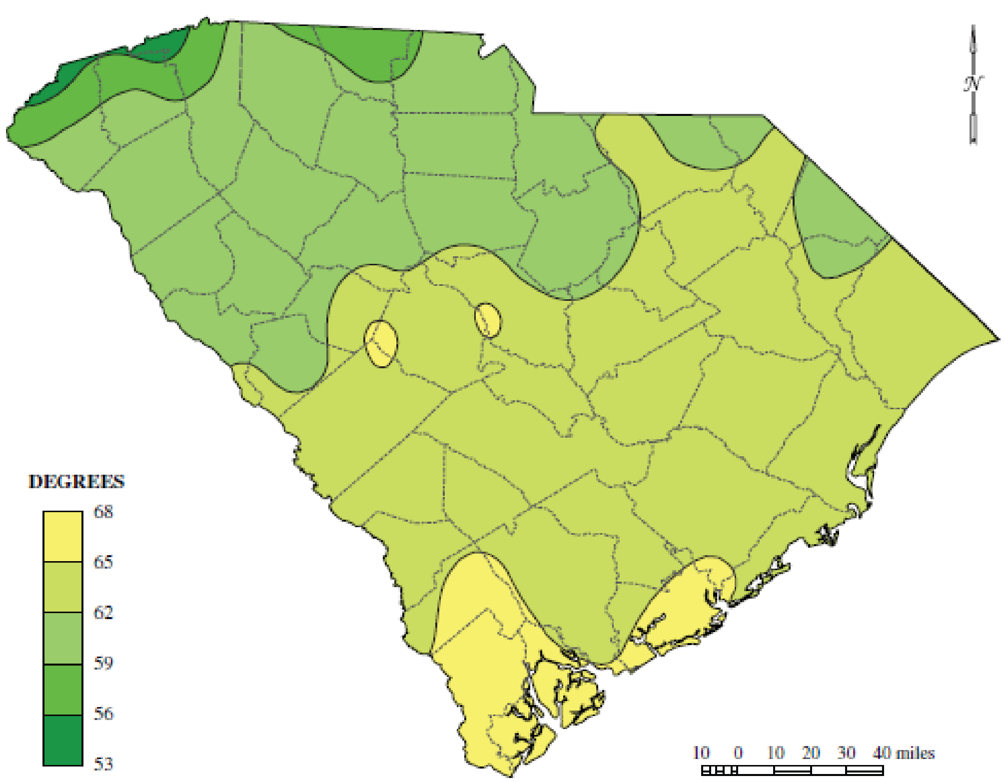
[43] Gellici, J.A., M. Kiuchi, S.L. Harwell, and A.W. Badr (2004), Hydrologic Effects of the June 1998-August 2002 Drought in South Carolina, South Carolina Department of Natural Resources Open File Report, Columbia, S.C.

[44] South Carolina Department of Natural Resources On-line Archived Drought Status, http://www.dnr.sc.gov/climate/sco/Drought/drought_press_release.php, 2008.

over coastal water is cooler than the air over land in summer and warmer than the air over land in winter, thus providing a moderating influence on temperatures at locations near the coast. Records show maximum temperatures along the coast to average 4-5°F (2°C) lower than maximum temperatures in the central part of the State. The record high temperature, 111°F (44°C), has occurred in central South Carolina 3 times: at Calhoun Falls on September 8, 1925; at Blackville on September 4, 1925; and at Camden on June 28, 1954. January is the coldest month, with monthly normal temperatures ranging from 39°F (4°C) at Caesars Head to 51°F (11°C) at Beaufort. July is the hottest month, with monthly average temperatures ranging from 72°F (22°C) at Caesars Head to 82°F (28°C) at Charleston.

The growing season for most crops is limited by fall and spring freezes and ranges from 200 days in the coldest areas to about 280 days along the south coast. In areas where most of the major crops are grown, the growing season ranges from 210-235 days. The average date of the last freezing temperature in spring ranges from March 10 in the south to April 1 in the north. Fall frost dates range from late October in the north to November 20 in the south. Minimum temperatures of less than 32°F (0°C) occur on about 70 days in the upper portion of the state and on 10 days near the coast. The central part of South Carolina has maximum temperatures of 90°F (32°C) or more on about 80 summer days. There are 30 such days along the coast and 10-20 in the mountains.

Figure 2.4 South Carolina average annual temperature, 1971-2000.



2.4.3 Severe Weather

Severe weather in the form of violent thunderstorms, hurricanes and tornadoes occurs occasionally. Thunderstorms are common in the summer months, but violent storms usually accompany squall lines and cold fronts in the spring. These storms are characterized by lightning, hail, high winds and they sometimes spawn tornadoes. Most tornadoes occur from March-June, with April being the peak month. In the 61-year period 1950-2010, South Carolina averaged 15 tornadoes per year. The majority of these tornadoes (81%) were short-lived EF-0 and EF-1 tornadoes on the Enhanced Fujita scale.[45] Stronger, more destructive tornadoes are rare, but do occur with a consistent annual frequency of 2-4 per year. Since 1950 eleven destructive EF-4 tornadoes have touched down in South Carolina with wind speeds of 166-200 miles per hour.

Tropical cyclones affect the South Carolina coast on an infrequent basis, but do provide significant influence annually through enhanced rainfall during the summer and fall months. Depending on storm intensity and proximity to the coast, tropical systems can be disastrous. Historically, hurricanes are more frequent in late summer and early fall; however, tropical cyclones have affected South Carolina as early as May and as late as November. From the late 1800s-2010, 171 tropical cyclones have affected the state. South Carolina has experienced 3 major hurricanes since the 1950s: Category 4 Hazel on October 15, 1954; Category 3 Gracie on September 29, 1959; and Category 4 Hugo on September 21, 1989.

2.4.4 El Niño-Southern Oscillation Influence on South Carolina's Climate

The Palmetto State's climate is complicated by a number of oscillations in the global atmosphere and ocean that can shift and alter distant weather patterns. There are many of these oscillations, some better known and studied than others: Quasi-Biennial Oscillation (QBO), Madden-Julian Oscillation (MJO), El Niño-Southern Oscillation (ENSO) and Atlantic Multi-Decadal Oscillation (AMO). Each oscillation can interact with others to provide a complex forcing for downstream sensible weather. Thus, changes in these oscillations and their interactions produce changes in regional climate.

The ENSO with embedded Kelvin waves is the best understood oscillation. ENSO is a coupled atmosphere-ocean circulation pattern that induces teleconnections in the Northern Hemisphere atmosphere, complicating South Carolina weather and climate by shifting the position of the jet stream. The ENSO has 3 phases: warm, neutral and cold. El Niño is the warm phase of the ENSO and is characterized by abnormally warm ocean water occurring along the coast of Peru and eastern equatorial Pacific Ocean. The ENSO cold phase, La Niña, is characterized by a deep pool of abnormally cold water across the eastern equatorial Pacific affecting upper atmospheric circulation patterns. During the El Niño portion of ENSO, increased precipitation falls along the Gulf Coast and Southeast due to a stronger than normal, and more southerly, polar jet

[45] http://www.spc.noaa.gov/efscale/. Last accessed May 2011.

stream.[46] During La Niña events, the storm track is shifted northward. Analysis of past La Niña winter events indicates that South Carolina weather was warmer and drier than the weather observed during neutral or El Niño events. Periods of severe to extreme drought experienced in South Carolina during 1954, 1988, 1998-2002 and 2007-08 are correlated with La Niña events in the Eastern Pacific Ocean. There is no clear periodicity of these drought-producing events. Conversely, El Niño winters in South Carolina on average tend to be wetter and cooler than the weather during neutral or La Niña events.

2.5 Analyzing South Carolina Climate Trends

A major hurdle for any climate study is locating a long-term continuous record of observational data. The National Oceanic and Atmospheric Administration United States Historical Climate Network (USHCN) is a well-documented, accurate source of daily and monthly state climate data for the period 1895-to the present. These data consist of minimum, mean and maximum temperatures and precipitation totals measured at 28 stations located across the state and provide the longest record of weather conditions in South Carolina.

To evaluate climate variability in South Carolina, a first-order analysis of the annual mean monthly USHCN temperature data was performed. Temperature data recorded at the Greenville-Spartanburg (GSP) Airport in Greer, University of South Carolina (USC) in Columbia, Beaufort and Georgetown were used to investigate trends in temperature variability. These stations were selected to represent the three major geographic divisions of South Carolina: mountains-piedmont, midlands-sandhills, and coastal plain. The data from these 4 climate observing stations revealed similar temperature trends that are presented in Figures 2.5-2.8.

After a pronounced cool period occurring from 1895-1904, a net average warming period occurred at USC, Beaufort and Georgetown (Fig. 2.5-2.8). During the 1905-1938 warming trend, mean temperatures at GSP rose rapidly in the first 8 years, remaining neutral until 1958 (Fig. 2.5); the GSP data demonstrated the cooling trend lagged approximately 10 years behind the other stations studied. Another pronounced cooling period is observed in the coastal station data from the period 1948-1968. This cooling period also is noted in the data collected at USC.

Of particular importance in the discussion over climate change is the good agreement of a warming trend beginning in 1970 to the present for all 4 stations. This warming trend is most pronounced in the GSP and Beaufort data sets.

[46] Climate Prediction Center, El Nino and La Nina-related Winter Features over North America, http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensocycle/nawinter.shtm. Last accessed Dec 2010.

Figure 2.5 Annual mean temperatures at Greenville-Spartanburg Airport (GSP), South Carolina, 1895-2010.[47]

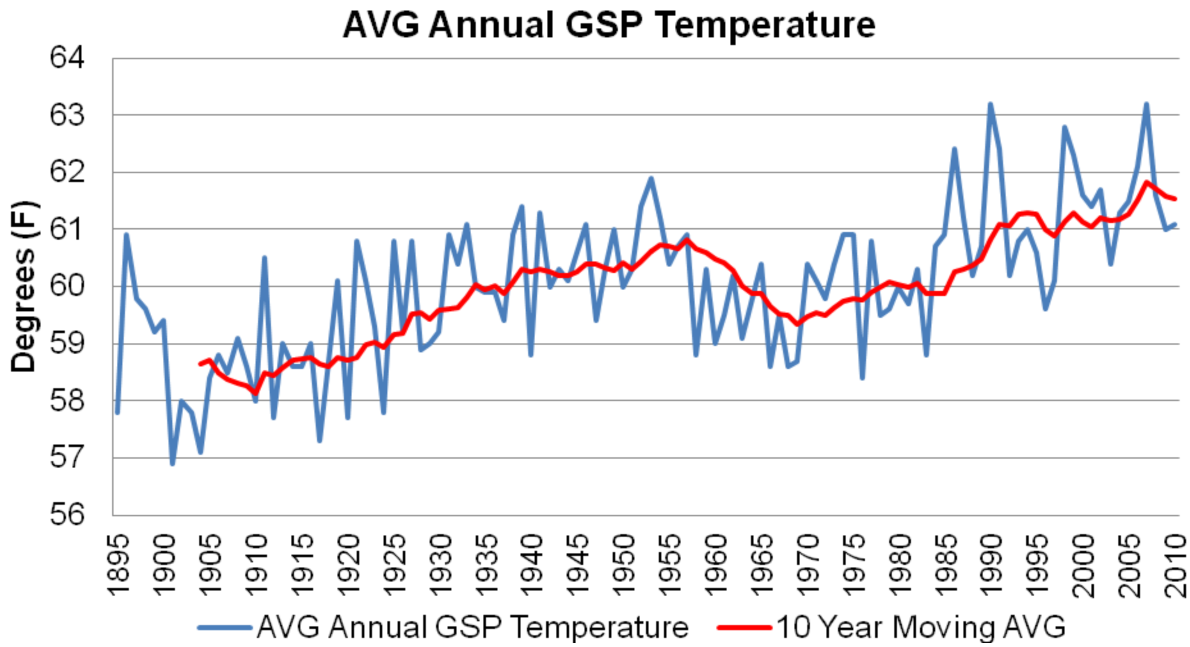
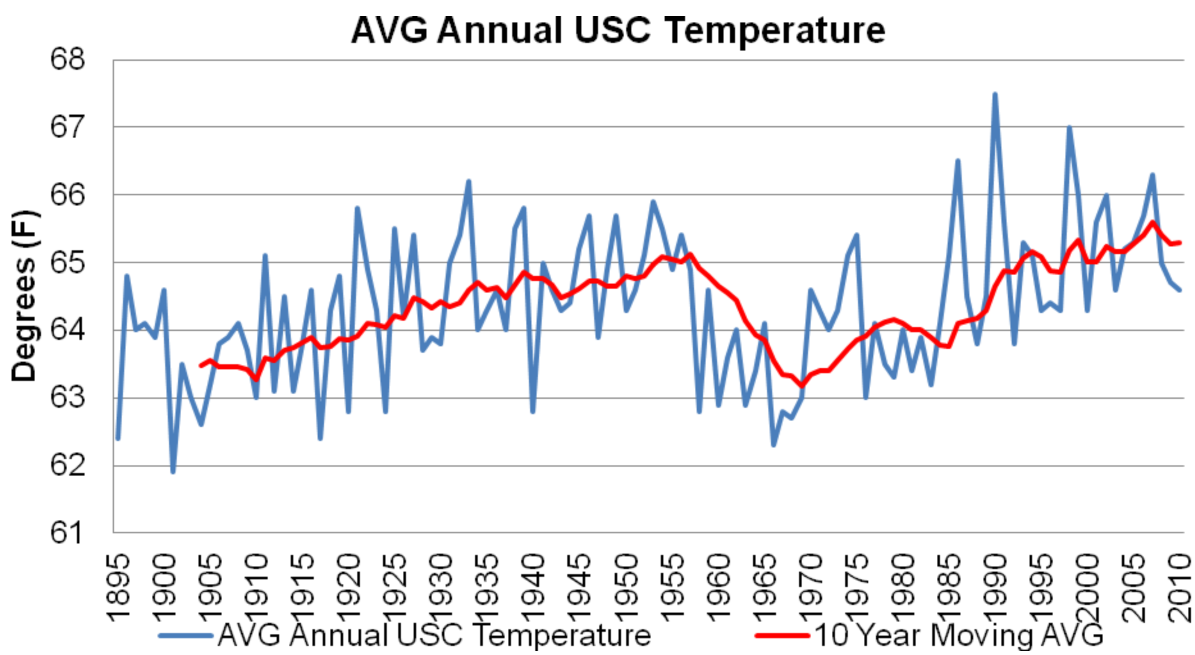


Figure 2.6 Annual mean temperatures at University of South Carolina (USC), Columbia, South Carolina, 1895-2010.[48]



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[47] National Oceanic and Atmospheric Administration Climate Research Data. The Daily Historical Climatology Network

http://www.ncdc.noaa.gov/oa/climate/research/ushcn/ushcn.html . Last accessed July 2010. Hereinafter NOAA/USHCN.

[48] NOAA/USHCN.

Figure 2.7 Annual mean temperatures at Beaufort, South Carolina, 1895-2010.[49]

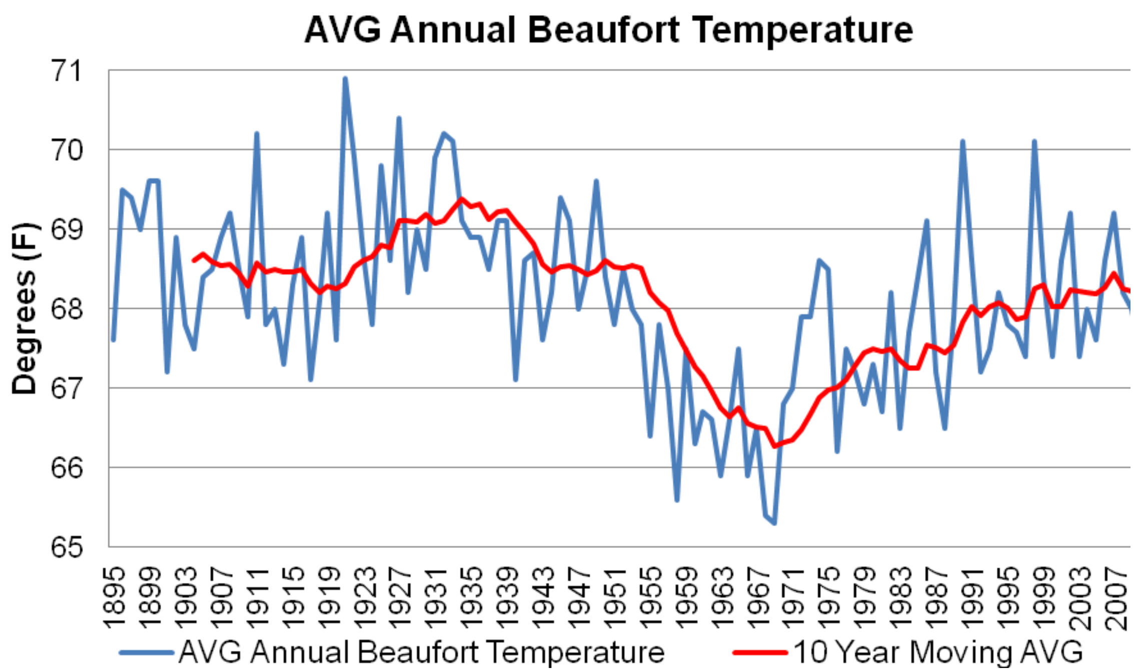
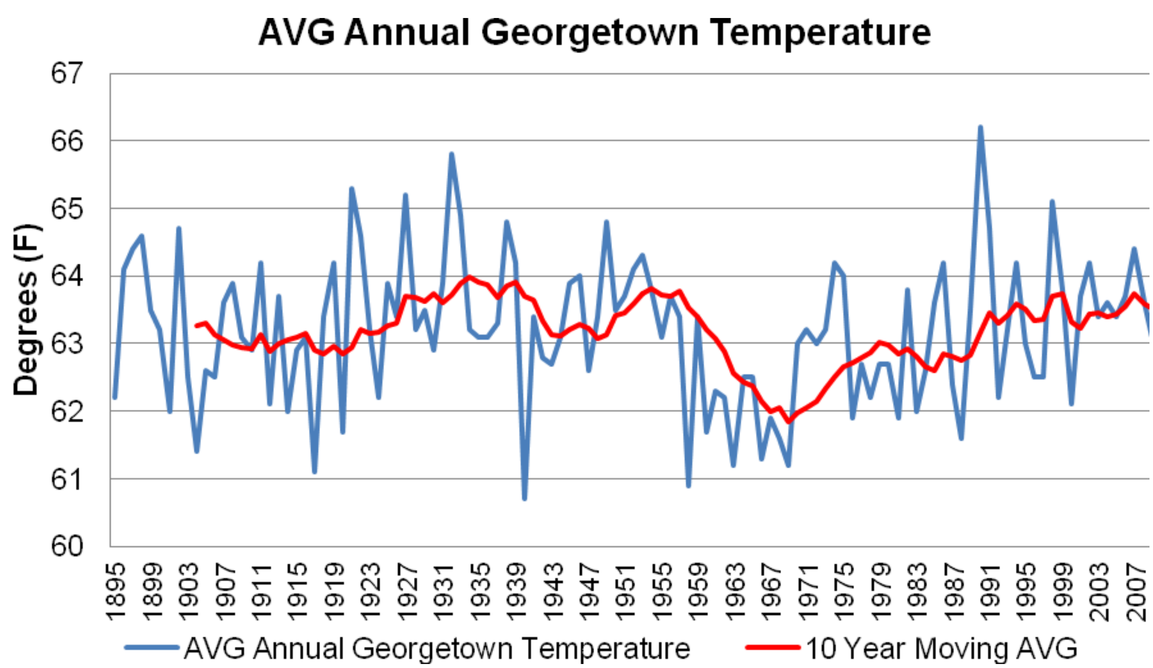


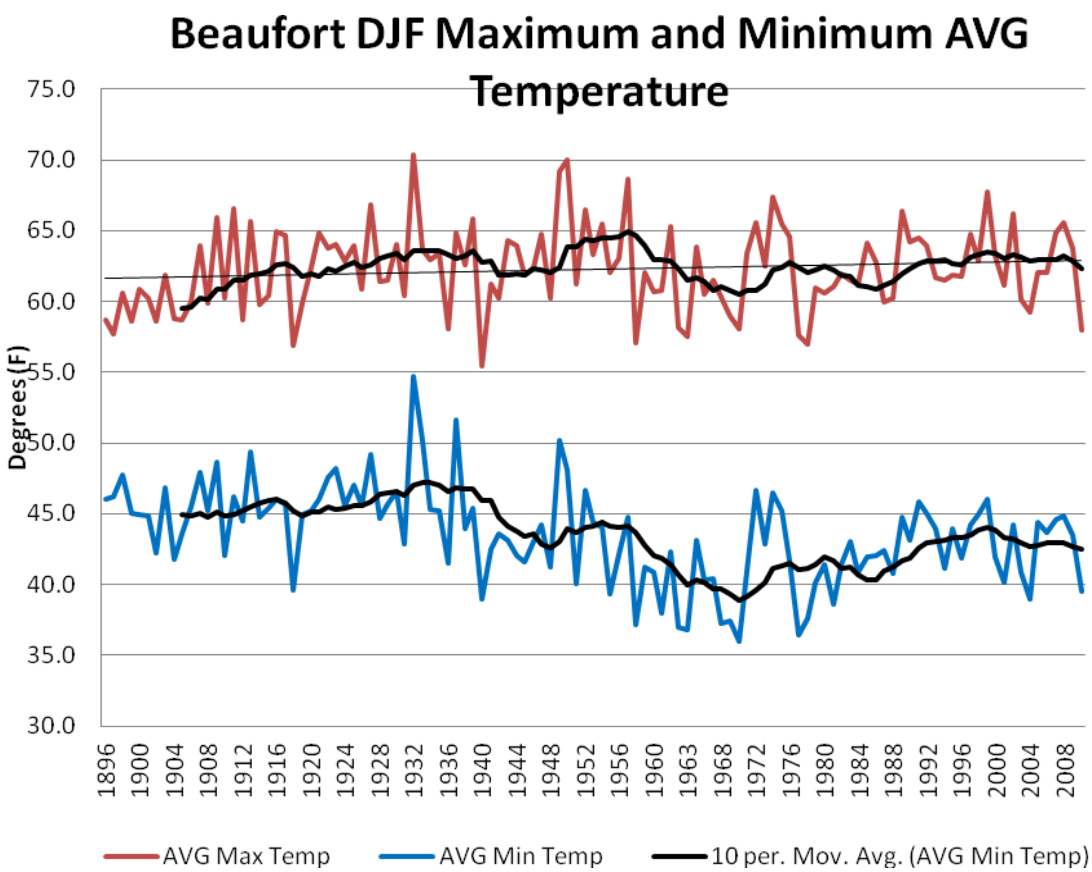
Figure 2.8 Annual mean temperatures at Georgetown, South Carolina, 1895-2010.[50]



[49] NOAA/USHCN.
[50] NOAA/USHCN.

USHCN data for Beaufort were investigated further to explore winter temperature trends. The December-January-February (DJF) monthly mean temperature data were plotted for the period of record 1896-2010 (Fig 2.9). Winter maximum temperatures demonstrated a slight warming trend for the period and conversely, minimum winter temperatures showed a very slight cooling trend. The long-term winter temperature trend was similar to the cool-warm-cool-warm trend seen in Beaufort's annual mean temperature data presented in Figure 2.7.

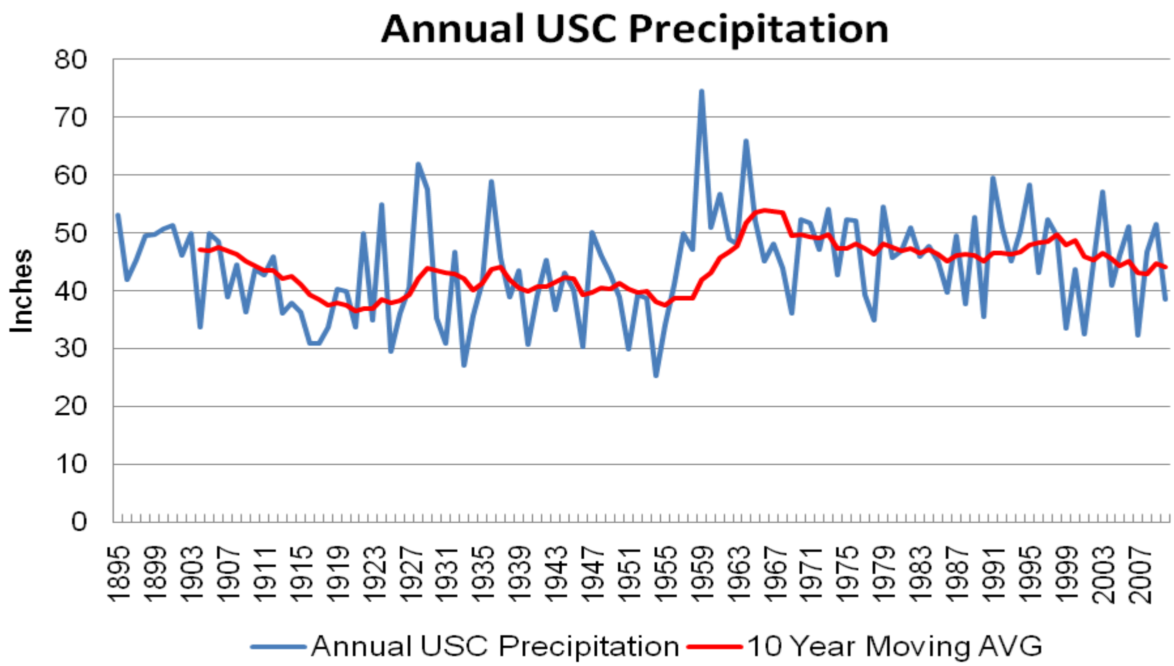
Figure 2.9 December, January, February average and median air temperatures recorded in Beaufort, South Carolina, 1895-2010.[51]



Examination of the USHCN annual rainfall data for the 5 stations showed no discernible trends, as shown, for example, in Figure 2.10. Lengthy periods of drought were evident in the data record as well as years with precipitation maxima. Some of the wetter years coincided with tropical cyclone activity, which can deliver a quarter to a third of the total annual rainfall amount in a single tropical storm event. There was poor correlation of the precipitation data and the annual temperature data (Fig 2.6, 2.10).

[51] NOAA/USHCN.

Figure 2.10 Cumulative annual precipitation, USC, Columbia, South Carolina, 1895-2010.[52]

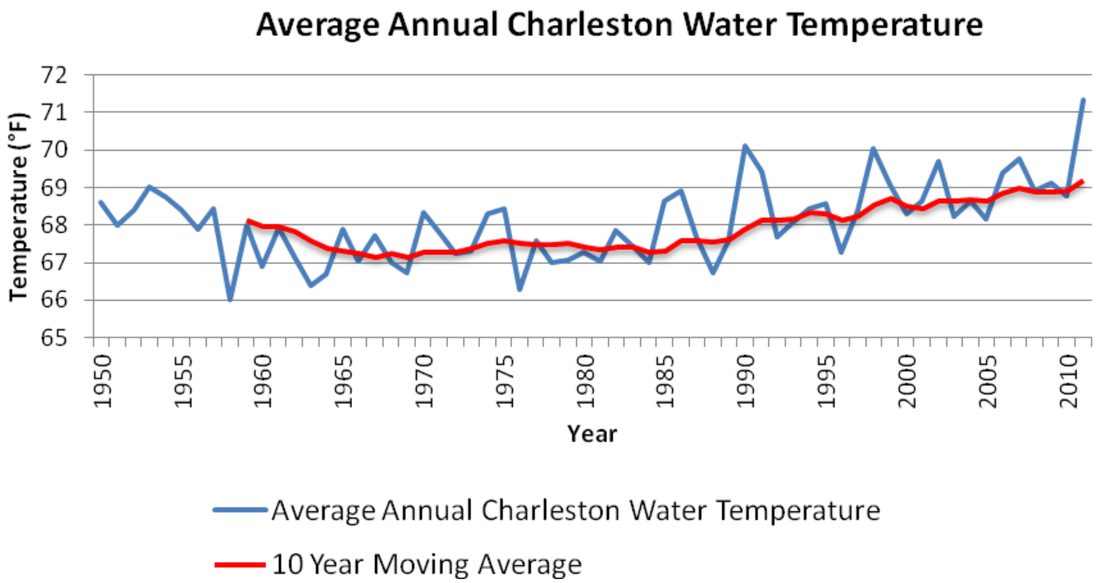


In addition to the temperature and precipitation study, a trend analysis of annual sea-water temperature data was completed using annual water temperature samples collected from the Charleston Harbor (Figure 2.11). The 10-year moving average of annual Charleston water temperature (Figure 2.11) shows relatively constant water temperatures from 1970 through 1985 before a steady warming trend began in 1985.

Data on severe storms were examined to discern any trends in severe storms. These data proved to be problematic due to the subjective nature of calculating the number of storm reports. Tornadoes and coastal hurricane landfalls provide a more objective measure to evaluate trends and variability; however, each has some inherent limitations. Tornado data from the period 1950-2010 (Fig. 2.12) demonstrate an increasing trend in these severe storms. This increasing trend is believed to be due to improved communications and detection capability, rather than climate change, and is attributable to increased population levels and the advent of Doppler radar technology in the early 1990s.

[52] NOAA/USHCN.

Figure 2.11 Average annual water temperature for Charleston, South Carolina, 1950-2010[53]



A tally of tropical cyclones making landfall along the South Carolina coast from 1878-2010 was plotted with a 10-year moving average calculation in order to note any trends (Fig. 2.13). Despite improvements in satellite technology, which can identify tropical cyclones, and indications that coastal water temperatures may be increasing, there is no evidence that tropical cyclone activity has increased along the South Carolina coast over the last 122 years .

[53] South Carolina Department of Natural Resources, Marine Resources Division

Figure 2.12 Annual observed South Carolina tornadoes, 1950-2010, demonstrating a Linear trend. [54]

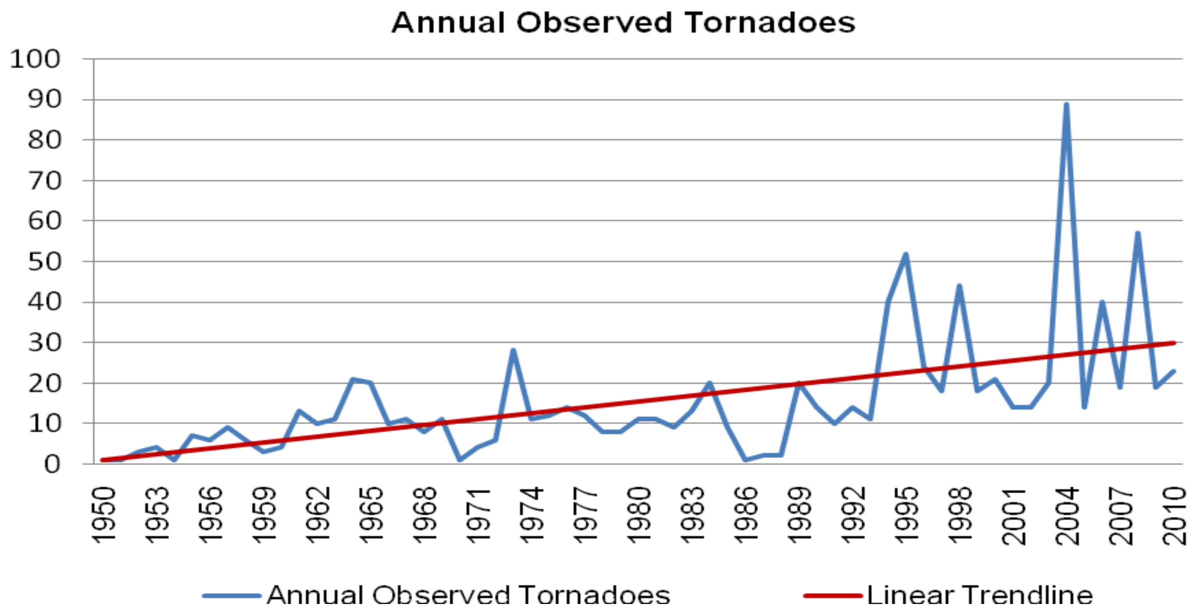
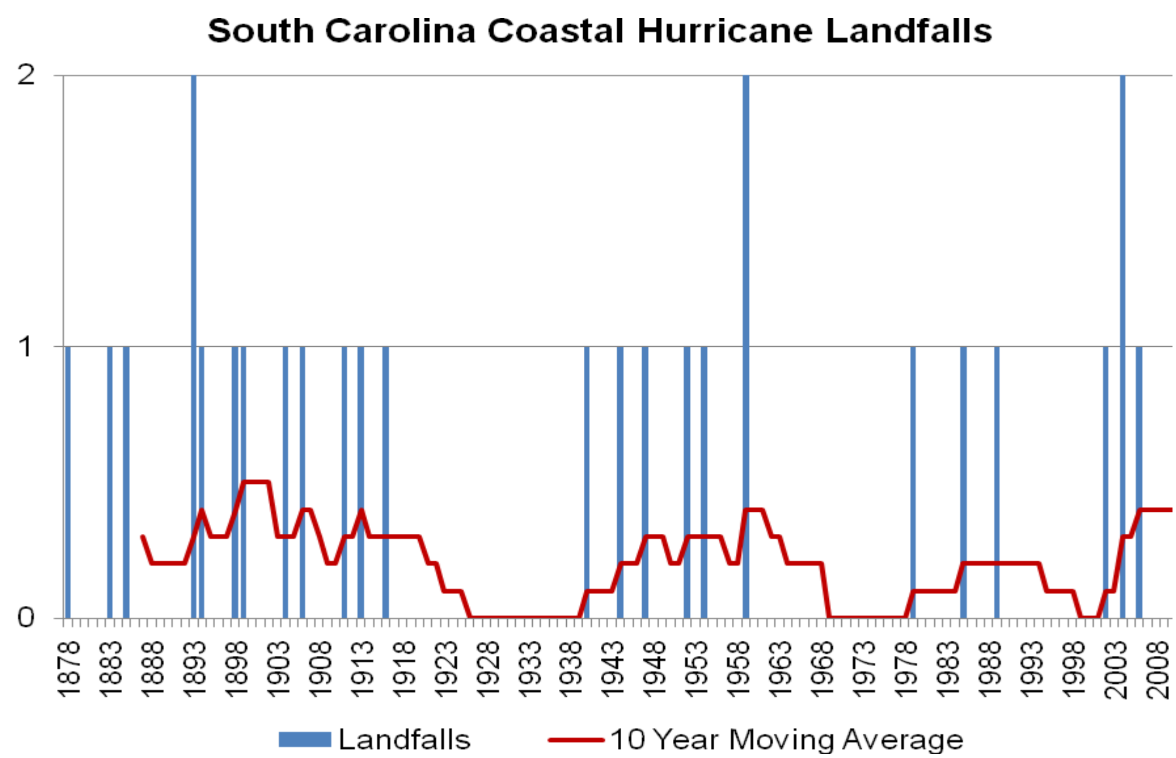


Figure 2.13 South Carolina coastal hurricane landfalls with a 10-year moving average applied.[54]



[54] http://www.nhc.noaa.gov/pastall.shtml. Last accessed Sept 2010.

2.6 Conclusions Based on South Carolina Data Examination

Temperature and precipitation data provide a record of variations in South Carolina climate extending back into the late 1800s. Air-temperature data from 1970 to the present show a steady increase in mean annual temperatures. Coastal water temperatures also support the recent warming phase, but the water temperature data record is not as extensive and continuous as the air temperature data. At this time, there is no definitive signal that tornadoes and hurricanes making landfall are increasing in the state. It must be noted that there is uncertainty in drawing broad conclusions on the recent and future climate of South Carolina based on examination of these kinds of localized data sets. In order to reduce uncertainty, more comprehensive data sets collected over a longer period of time and covering a larger geographic area must be examined.

2.7 Examination of Regional Climate Data and Predictive Models

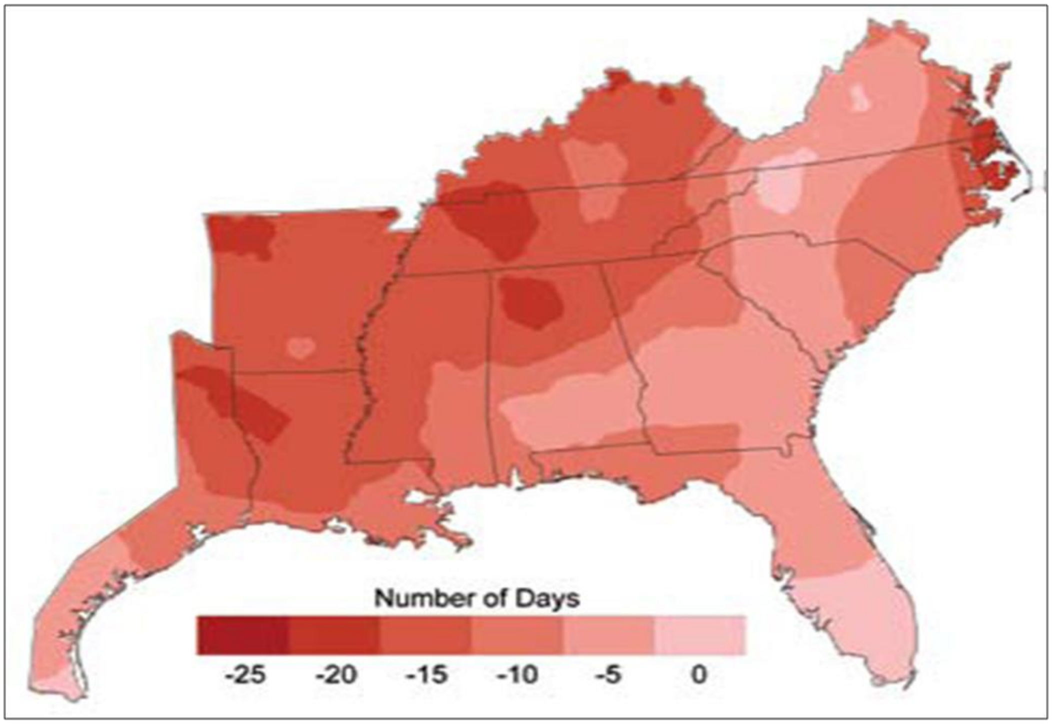
The southeastern United States may be particularly vulnerable to climate change because of the risks associated with its low-lying coastline, periodically occurring winter storms and tropical systems.[55] The rich biodiversity of the Southeast could be exposed to more risks related to drought, plant and animal pathogens and invasive species. The Southeast is home to more than 400,000 farms on almost 80 million acres (32 million ha),[56] over 127 million acres (51 million ha) of timberland[57] and 33% of estuaries[58] and almost 30% of all wetlands in the conterminous United States.[59]

Since it is harder to examine climatic trends at the state level variations over the past in order to make climatic predictions, it is important to examine regional climate trends and models. Compared to the continental United States, the climate of the Southeast is uniquely warm and wet, with mild winters and high humidity. Southeastern average annual temperature has exhibited natural variation for most of the past century; however during the past 40 years annual average temperature has increased about 2°F (1°C).[60] The greatest seasonal change has occurred during winter with freezing days declining 4-7 days per year over the period (Fig. 2.14). Changes in precipitation have been occurring over the past 3 decades with increases in heavy downpours in many parts of the Southeast, even though much of the region has experienced moderate to severe droughts during the same period.[61] While there is uncertainty in projecting trends in

[55] Karl, T.R., J.M. Melillo, and T.C. Peterson (eds.). 2009. Global Climate Change Impacts in the United States. Cambridge University Press, New York.
[56] USDA. 2008. Data Sets: Regional Agricultural Profile System. USDA Economic Research Service. Presentation tool for the 2002 Census of Agriculture. http://www.ers.usda.gov/data/RegionMapper/index.htm. Last accessed July 2010.
[57] USFS. 2010. Stream Temperature Modeling. US.Forest Service. http://www.fs.fed.us/rm/boise/AWAE/projects/stream_temperature.shtml. Last accessed June 2010.
[58] NOAA. 1990. Estuaries of the United States: Vital Statistics of a National Resource Base. Monograph. NOAA National Ocean Service, Strategic Assessment Branch, Rockville, MD.
[59] Dahl, T.E. 1990. Wetland Losses in the United States 1780s to 1980s. US Department of the Interior, Fish and Wildl. Serv, Washington, DC. 167 pp.
[60] Regional Climate Impacts: Southeast. USGCCRP 2009. http://www.globalchange.gov/images/cir/pdf/southeast.pdf. Last accessed Aug 2010. Hereafter USGCCRP 2009.
[61] USGCCRP. 2009.

tropical activity, it is important to address that changes in tropical intensity and frequency has the potential for major implications.

Figure 2.14 Change in freezing days per year from1976 to 2007 in the southeastern United States demonstrating that since the mid-1970s the number of days per year during which the temperature falls below freezing has declined by 4-7 days over much of the Southeast but over 15 days for much of Arkansas, Louisiana, Mississippi and Tennessee.[62]



Current climate models predict continued warming across the Southeast with the rate of warming more than twice the current rate. The greatest temperature increases are projected to occur in the summer months. The number of very hot days of $\geq$ 100°F (38°C) is projected to rise at a greater rate than the average temperature. Under the lower GHG emissions scenario average temperatures in the Southeast are projected to rise by about 4.5°F (2.5°C) over the next 70 years, while a higher GHG emissions scenario is predicted to yield about 9°F (5°C) of average warming. Summers by the 2080s are projected to be about 11°F (6°C) hotter with a much higher heat index. The frequency, duration and intensity of droughts are likely to continue to increase with higher average temperatures and a higher rate of evapotranspiration.[63]

Interest in the effects of climate change in the Southeast is increasing, but there are any number of impediments to understanding and predicting climate change, including public apathy and a lack of awareness, lack of outreach on adaptation options, lack of

[62] USGCCRP. 2009.
[63] USGCCRP. 2009.

uniform access to information on current climate change risks and a lack of guidance on what information and tools are available. Climate change documentation and development of adaptation strategies also are limited primarily by a lack of funding, a lack of political will and lack of government leadership. Leadership issues may be a result of division of authority across topics as well as geographic and political boundaries across federal, state and municipal governments. All of these factors impede development of effective climate change adaptation policies across the Southeast.[64]

2.8 Climate and Weather Assessment

How will climate change affect day-to-day weather conditions, and how will these weather changes impact South Carolina natural resources and their public use and enjoyment? Can we monitor climate change at useful scales? The recognition and description of climate change and weather patterns are vital to the management of natural resources.

Detailed information about temperature, soil moisture, precipitation and humidity, when combined with long-term weather models and historical climate data, provide valuable information, such as duration of droughts and shifts in the duration of seasons. In turn, this information is used to help citizens in many ways. An important application of accurate climate data is monitoring the shift in frost-free days. An accurate, statewide monitoring system should be integrated with a warning system to alert local officials and citizens when temperatures or weather conditions become hazardous.

Extreme weather events are also of concern. For example, it has been proposed that climate change can influence the intensity and number of storm events.[65] Although supporting data are not entirely conclusive, the physics behind models are well understood. Warmer ocean temperatures potentially can provide more energy to hurricanes, leading to more intense storms. Increased precipitation patterns could have an adverse affect on flooding issues. High intensity rainfalls could lead to greater flooding hazards and mud- or landslides.

Enhanced support is needed for weather-station systems to forecast short-term events and monitor longer term trends. Weather stations that have reliable, long-term homogeneous data provide data needed for the detection and attribution of present and future climate change. Costs and maintenance associated with these systems require partnerships between federal, state and local governments and non-governmental organizations (NGOs). There needs to be a stable, long-term commitment to these weather station systems and to the monitoring and management of the data.

Our understanding of climate change also can benefit from paleoclimate studies. Past climates can indicate the potential range of physical and biological conditions we might

[64]USEPA. 2010. Report on the USEPA Southeast Climate Change Adaptation Planning Workshop. http://epa.gov/region4/clean_energy/Task.5.Report.05.10.2010.pdf. Last accessed Sept 2010.
[65]H. Tompkins. 2002. Climate change and extreme weather events: Is there a connection? Cicerone 3:1-5.

expect. Paleoclimate studies also can provide insight into rates of climate change, conditions prior to major changes and the overall effect to the landscape resulting from climate change. Several lines of research could provide detailed information about past climates. For example, the stratigraphic record in the coastal plain can provide information about sea-level positions, minimums, maximums and rates of change. Carolina bays are known to have detailed fossil assemblages that can help interpret climatic conditions. Coastal lagoons may contain evidence of ancient hurricanes, providing information about the number, age and intensity of storms in the past. The study of ancient hurricanes (paleotempestology) could provide useful information about the frequency and intensity of hurricanes affecting South Carolina during the past. This information could be related to climatic conditions anticipated over the next several decades.

Climate change has the potential to increase flooding events requiring up-to-date flood mapping. The potential for increased flooding events or increased magnitude of flooding events or both could diminish the accuracy of current flood-plain maps. A strong flood-mapping program is needed. Through climate and stream monitoring, DNR may be able to better understand increased hazards, translate the results into a new generation of flood maps and design better emergency response programs.

3.0 CLIMATE CHANGE IMPACTS TO NATURAL RESOURCES IN SOUTH CAROLINA

3.1 Potential Physical Effects Resulting from a Changing Climate

3.1.1 Potential Effects Related to Change in Sea Level

3.1.1.1 Sea-level Rise

Sea level is rising,[66] and whatever the cause, it is a serious concern.[67] The evidence for the rise is visible to anyone who visits the beach. Communities have seen their shoreline retreat, requiring an increased need for beach nourishment. Along some beaches, downed trees and drowned tree stumps are an obvious sign of shoreline retreat. One of the most pronounced effects of sea-level rise will be the effects on shoreline and estuarine habitats and the species that depend on them. Sea-level rise and land subsidence also will affect coastal zone development. Shoreline change takes several forms: erosion, deposition and migration. Monitoring changes in magnitude, direction and rates of these parameters will provide important information to policy and decision makers. Beaches are among the most economically valuable natural resources in South Carolina, and the frequency of beach nourishment projects has accelerated over the past several decades. Impacts to beaches could be exacerbated by increasing intensity and frequency of damaging tropical storms, as predicted under some climate

[66] IPCC. 2007.
[67] EPA, 1989: The Potential Effects of Global Climate Change on the United States. Report to Congress. US Environmental Protection Agency. EPA 230-05-89-052. 401 pp. http://www.epa.gov/climatechange/effects/downloads/potential_effects.pdf. Last accessed Aug 2010.

change scenarios. While the magnitude of sea-level rise expected over the next century is not known with certainty, most models project approximately a 2.0 feet (0.6 m) rise. Estimates of sea-level rise have used multiplier factors ranging from 20-100 to estimate landward intrusion, indicating a potential intrusion boundary of 39-197 feet (12-60 m)[68] – clearly placing much of current beach development in South Carolina in jeopardy. In addition, outflow of coastal rivers, which act as a sand replenishment source, has been altered through more than a century of dam and hydroelectric reservoir development, the Santee and Pee Dee rivers being good examples. Not only are the physical threats of shoreline loss important, but the natural beauty of coastal beaches and the wildlife they sustain are extremely important to the state's economy and cultural heritage, and their sustainment is in doubt.

3.1.1.2 DNR Response and Recommendations

A comprehensive shoreline change strategy is needed to define the rate and magnitude of relative sea-level rise, as well as associated effects including shifting shoreline position, erosion rates and shifting salinity. Consideration of vegetation and aquatic organisms also is important to assess ecosystem change. Tracking sea-level rise and concomitant coastal change is a substantial task, but it is most effective when performed in cooperation with other state, federal and local efforts. Partnerships will be needed to acquire and protect habitat, as well as to collect, host and share regional, specific coast-wide data.

3.1.1.3 Coastal Habitats Affected by Sea-level Rise

The coastal zone is home to a number of unique habitats that are critical to support important wildlife and marine species. These include hammocks, salt and brackish emergent wetlands, that accommodate nesting, resting, and feeding areas for birds and beach dune systems where sea turtles (superfamily *Chelonioidea*) nest. These species and their habitats are especially vulnerable to the treat of sea-level rise.[69] [70]

South Carolina has several thousand small, unique coastal islands associated with larger barrier islands. The hammocks provide valuable resting and feeding stations for migratory shore birds as well as natural refuges for coastal mammals including deer, otter, mink and others. These small islands, ranging in size from less than an acre to several hundred acres, are most numerous between the Santee and Savannah rivers. Termed marsh hammocks or back barrier islands, they typically are located behind the oceanfront barrier islands and adjacent to the larger barrier islands. Other hammocks are located along the Atlantic Intracoastal Waterway or adjacent to coastal rivers and

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[68] IPCC. 2007.

[69] Daniels R. C., T. W. White and K. K. Chapman. 1993. Sea-level rise: destruction of threatened and endangered species habitat in South Carolina. Environ. Manage. 17: 373-385.

[70] Cheung, W., W. Vicky, J. Lam, K. Sarmiento, R. Kearney, R. Watson and D. Pauly. 2009. Projecting global marine biodiversity impacts under climate change scenarios. Fish and Fisheries. 10(3):235-251.

estuaries. Almost all are surrounded by expanses of salt marsh, occasionally being bordered by tidal creeks or rivers.[71]

Sea-level rise poses the following risks to hammocks:

1. Low elevation (< 0.3 meters in some cases) increases susceptibility to even modest sea-level rise,
2. They provide preferred habitat for biota requiring freshwater ponds or wetlands for reproduction and are sensitive to sea-water intrusion, and
3. Increased demand for marsh front or water front property has made these formerly unattractive and inaccessible areas economically attractive for development.

Sand dunes and beach habitat on the South Carolina coastline are vital for nesting of sea turtles, including the loggerhead sea turtle (*Caretta caretta*) and for feeding of sea birds. It is widely accepted that most female sea turtles return to their natal region every 2–3 years to nest.[72] Because of this vital link in their natural history, loss of front beach nesting habitat to beach erosion is a serious problem for this threatened species. Furthermore, since beach erosion is typically exacerbated by sea-level rise, rising water levels clearly pose a long-term threat to sea turtle populations. If beach erosion occurs on undeveloped islands, impacts to sea turtles may be minimal as the island simply retreats. However, aerial observations suggest that undeveloped islands in South Carolina are not retreating in a manner that would sustain turtle nesting because erosion is occurring at such a rapid pace.[73] *Bone yards or* dead tree trunks and limbs in the surf zone, exposed peat from geologically older marshes and a general loss of sand, due to dams on major rivers and nourishment projects, all appear to be diminishing the nesting quality of these beaches.[74] Although nourishment on developed beaches can restore some beach function as a nesting area, steep scarps sometimes develop just above the surf zone preventing female sea turtles from nesting or limiting them to lower sites where nests are vulnerable to tidal inundation and wave action.[75] Additionally, research indicates the nourishment process creates significant disruption to the physical and biological compositions of offshore sites where sand is mined and not replenished naturally.[76]

Estuarine flats, salt marshes and creeks form essential habitat to the juvenile stages of many marine species that support important inshore fisheries such as shrimp (*Litopenaeus* and *Farfantepenaeus*), blue crab (*Callinectes sapidus*), spot (*Leiostomus*

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[71] Whitaker, J. D., J. W. McCord, P. P. Maier, A. L. Segars, M. L. Rekow, N. Shea, J. Ayers and R. Browder. 2004. An ecological characterization of coastal hammock islands in South Carolina. Final report to Ocean and Coastal Resources Management, SC Dept. of Health and Environmental Control. SC Dept. Nat. Resour. Rept. 115 pp.

[72] Bjorndal, K. A., A. B. Meylan and B. J. Turner. 1983. Sea turtle nesting at Melbourne Beach, Florida, I. Size, growth and reproductive biology. Biological Cons. 26: 65-77.

[73] Dubose Griffin, DNR, personal communication.

[74] Dubose Griffin, DNR, personal communication.

[75] M. Steinitz, M. Salmon, and J. Wyneken. 1998. Beach renourishment and loggerhead turtle reproduction: A seven year study at Jupiter Island, Florida . J. Coast. Resour. 14(3):1000-1013.

[76] Posey M. and T. Alphin. 2002. Resilience and stability in an offshore benthic community: Responses to sediment borrow activities and hurricane disturbance. J. Coast. Resour. 18(4):685-697.

xanthurus), flounder (*Paralichthys spp.*), red drum (*Sciaenops ocellatus*), spotted seatrout (*Cynoscion nebulosus*) and gag grouper (*Mycteroperca microlepis*). These flats also sustain high densities of other small species, such as fiddler crabs (*Uca* spp.), snails and killifish (*Fundulus,* spp.), which are important prey for larger fish, crabs and birds. Rising sea levels could contribute to a reduction in the area of intertidal marsh available, especially if coastal development impedes their inland expansion in response to inundation. Reduced salt marsh area would be expected to have a negative impact on the populations of species that rely on salt marsh habitat.

3.1.1.4 DNR Response and Recommendations

The effects of rising sea level and its biological ramifications are at best uncertain and potentially devastating to the coastal zone ecosystem. Substantial resources need to be dedicated to reducing these uncertainties. Support should be given to spatial mapping projects that can model the effects of sea-level rise and assist in identifying methods of reducing its impacts.

Migratory routes and utilization of hammock islands by birds should be quantitatively compared to the mainland and the larger barrier islands. In order to determine relative abundance of birds and mammals, utilization of truly isolated hammocks should be compared to the more accessible hammocks. Other research interests include the importance of woodland edges for birds, the influence of the physical shape on bird utilization (complex shorelines vs. a circular-shaped island), predator-prey interactions and the interrelationships between plants and animals should be studied. Efforts should be made to ensure that land is set aside to serve as isolated hammocks as salt marshes migrate inland as a result of rising sea level.

Cooperative studies and management efforts with beachfront communities should continue to ensure the protection and enhancement of sea turtle nesting beaches. The rate of sea-level rise should be monitored, and resultant information should be used to determine appropriate management options as conditions change. Long-term management plans for beach nourishment should be developed through collaboration among beach communities, researchers and state/federal agencies. These plans should included examination and identification of likely renewable sand resources, beach nourishment funding sources and beach nourishment impacts upon other natural resources.

3.1.1.5 Sea-level Rise Effect on Marine and Coastal Resources

Implications of sea-level rise will require societal considerations that will have both direct and indirect effects on marine and coastal resources. Regarding the gradual inundation of beaches, river banks, and marsh edges, only three basic options are available: retreat inland, armor with sea walls or revetments or, in the case of beaches, nourishment by physically moving sand, usually from offshore. Each of these options has high economic costs as well as potential biological costs.

Sea-level rise could have profound effects on coastal salt marshes, inland brackish marshes and further inland freshwater marshes. Some believe that marshes, with time, can migrate inland and maintain their viability;[77] however if development and armored shorelines prevent potential inland retreat, marsh area will be reduced along with associated living marine resource productivity. Even without the opportunity for marshes to migrate landward, studies in South Carolina have shown that some salt marsh habitats may be resilient to sea-level rise due to sufficient sedimentation that allows the marshes to rise with sea level, while other marsh habitats will not be able to do so, resulting in drowning of those marshes. Similar problems could occur in the state's valuable shellfish beds if the beds cannot migrate landward, or changes in existing habitat conditions destabilize the beds.

If populations that are targeted by recreational and commercial fishing are negatively impacted by climate change, particularly loss of estuarine nursery habitat, mitigation in the form of aquaculture replenishment stocking or for pond grow out of seafood may be in greater demand.

3.1.1.6 DNR Response and Recommendations

Efforts should be undertaken to proactively address marsh migration through the use of migration models that identify likely areas where marshes could migrate. On the basis of these models, strategies should be cooperatively developed to protect these areas from further and future development. Research and development of mariculture techniques for important fishery species should continue or be initiated.

3.1.1.7 Sea-level Effects on the Fresh and Saltwater Interface

Changes in the location of the saltwater/freshwater interface will affect many freshwater and diadromous fish species. As sea level rises, saltwater will move further up the river systems of the state. Species with low salt tolerances and diadromous fish will be limited in their ability to move upstream into better quality habitat due to dams and hydroelectric reservoirs constructed on most South Carolina riverine systems. The amount and distribution of aquatic vegetation also will change in response to increases in salinity, limiting cover and food sources for aquatic organisms. Additionally, the potential exists for increased demand for water releases from reservoirs to fight the salt wedge that will be moving inland.

3.1.1.8 DNR Response and Recommendations

For shifting salinity profiles, a contemporary, comprehensive hydrological survey of the coastal rivers is needed to determine existing and normal salinity patterns. Predictive models to analyze potential for salinity change by river mile should be developed throughout the coastal zone. Information obtained from sound scientific research could

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[77] Feagin, R. A., M. Luisa Martinez, G. Mendoza-Gonzalez and R. Costanza. 2010. Salt marsh zonal migration and ecosystem service change in response to global sea level rise: a case study from an urban region. Ecology and Society. 15(4):14. [online] URL: http://www.ecologyandsociety.org/vol15/iss4/art14/. Last accessed June 2011.

be used to support development of adaptive management strategies to cope with shifting salinity in coastal rivers.

3.1.1.9 Sea-level Rise Effects on Coastal Managed Wetlands

The coastal landscape of South Carolina has both beauty and ecological significance. Managed tidal wetlands, also known as *rice fields, diked marshes* and *coastal impoundments* are a unique category of tidal coastal wetlands that exist in substantial acreage in and primarily only in South Carolina, largely as relics of a long-past agricultural era. Predominantly occurring in the traditional freshwater tidal zone, the infrastructure of most of the original acreage of managed tidal wetlands has been abandoned for a variety of reasons. However, a portion of the original acreage of these historically, culturally and economically important habitats in the coastal landscape is maintained intact for utilization by migratory birds and for recreational hunting. Conservation of rice plantations and associated managed wetlands in South Carolina is unique and is the predominant basis for habitat protection initiatives enabling modern preservation of tens of thousands of acres of ecologically important wetlands and upland buffer.

Waterfowl migrate during autumn from northern production areas to southern wintering areas, then in spring return northward to nesting areas.[78] Southern wintering allows dispersal over a broad area resulting in diverse foraging opportunities and maintenance of body condition.[79] Optimum wintering waterfowl habitat such as that located within South Carolina managed tidal wetlands is critical to the maintenance of this national trust resource.

Rudimentary wetland habitat management strategies were improved during the period between 1945 and 1985 until they became highly refined and specific.[80] [81] [82] Numerous papers have described prescriptive water quality parameters and water level manipulations designed to produce standing crops of preferred naturally occurring emergent and submerged wetland plants in fresh, intermediate, brackish, saline and hypersaline marshes.[83] [84] [85] [86] [87] [88]

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[78] Welty, J. C. 1975. The life of Birds, 2nd edition. W. B. Saunders Co. Philadelphia, PA. 662 pp.

[79] Baldassarre, G. A. and E. G. Bolen. 1994. Waterfowl ecology and management. John Wiley & Sons, New York, NY. 609 pp.

[80] Gordon, D. H., B. T. Gray, R. D. Perry, M. P. Prevost, T. H. Strange and R. K. Williams. 1989. South Atlantic coastal wetlands. Pages 57-92 *in:* Habitat Management for Migrating and Wintering Waterfowl in North America, L. M. Smith, R. L. Pedersen and R. M. Kaminski, eds. Texas Tech University Press, Lubbock, TX. 574 pp. Hereinafter: Gordon et. al. 1989.

[81] Conrad, W. Brock. Conrad. 1966. A food habits study of ducks wintering on the lower Pee Dee and Waccamaw rivers, Georgetown, South Carolina. Proc. Annu. Conf. Southeast. Assoc. Game and Fish Comm, 19:93-99.

[82] W. P. Baldwin. 1950. Recent Advances in Managing Coastal Plain Impoundments for Waterfowl, An. Conf. SE Assoc. Game and Fish Comm. 11 pp.

[83] Williams, R. K., R. D. Perry, M. B. Prevost and S. E. Adair. 1998. Management of South Atlantic coastal wetlands for waterfowl and other wildlife. Ducks Unlimited, Inc., Memphis, TN. 26 pp.

[84] Morgan, P. M., A. S. Johnson, W. P. Baldwin and J. L. Landers. 1975. Characteristics and management of tidal impoundments for wildlife in a South Carolina estuary. Proc. Annu. Conf. Southeast. Assoc. Game and Fish Comm. 29:526-539.

[85] Landers, J. L., A. S. Johnson, P. H. Morgan and W. P. Baldwin. 1976. Duck foods in managed tidal impoundments in South Carolina. Journal Wildl. Manage. 40:721-728.

Coastal wetland managers have made significant strides in habitat management employing diverse, holistic habitat management plans that incorporate a wide variety of strategies to maximize production of favored plant material, seeds, and tubers and associated invertebrates while allowing for estuarine connectivity.[89] As a result of these successes some coastal landowners in the tidal regime constructed dikes in brackish and saline wetlands not previously included in rice culture.[90] By the mid-1970s over 70,000 acres (112,630 ha) of South Carolina coastal wetlands were in some form of wetland management primarily directed toward attracting waterfowl for recreational hunting and enjoyment.[91] Waterfowl since have flourished in managed tidal wetlands along with other wetland dependent wildlife, most notably shore and wading birds, the bald eagle (*Haliaeetus leucocephalus*) and the American alligator (*Alligator mississippiensis*).[92] DNR manages a total of 32,940 acres (13,331 ha) of managed wetlands at 6 locations that occur in the intertidal zone. The Yawkey Wildlife Center and Santee Coastal Reserve are located in Charleston and Georgetown counties and have dikes and wetlands that front directly on the ocean. These properties have 26.4 miles (42.5 km) and 15.8 miles (25.4 km) of perimeter dikes with 32 and 25 water control structures in these dikes, respectively. These 2 properties are under direct threat from sea-level rise. Existing dikes are minimally adequate in height and any rise will threaten the management of these wetlands. Bear Island WMA in Colleton County and Santee Delta WMA in Georgetown County are located more inland but will be affected by sea-level rise. They have 15.0 miles (24.1 km) and 5.8 miles (9.3 km) of perimeter dikes with 35 and 10 water control structures in these dikes, respectively. Samworth WMA located in Georgetown County and Donnelley WMA located in Colleton County are even further inland but still depend upon the tide to provide water for flooding of the wetlands. These 2 properties have 14.2 miles (22.8 km) and 0.7 miles (1.1 km) of perimeter dikes with 22 and 5 water control structures located in these dikes, respectively.

An embankment of sufficient composition and height is mandatory to seasonally restrict tide water from a managed tidal wetland; water control structures installed in embankments are necessary to adjust, raise or lower water levels in accordance with regularly occurring tides and a desired wetland management strategy.[93] Because the

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[86] Prevost, M. B., A. S. Johnson and J. L. Landers. 1978. Production and utilization of waterfowl foods in brackish impoundments in South Carolina. Proc. Annu. Conf. Southeast. Assoc. Game and Fish Comm. 32:60-70.
[87] Perry, R. D. 1987. Methods to enhance target species production in freshwater impoundments. Pages 33-43 *in*: M. R. DeVoe and D. S. Baumann, eds. SC Coastal Wetland Impoundments: Management Implications, Workshop Proc. SC Sea Grant Consortium. Tech. Rep. No. SC-SG-TR-87-1.
[88] Perry, R. D. 1995. Management of tidal freshwater wetlands for waterfowl. Pages D124-D134 *in*: W. R. Whitman, et al. eds. Waterfowl habitat restoration, enhancement and management in the Atlantic Flyway. Third ed. Environmental Manage. Co., Atlantic Flyway Coun. Tech. Sect. and Delaware Div. Fish and Wildl., Dover, DE.
[89] Gordon et. al. 1989.
[90] Miglarese, J. V. and P. A. Sandifer, eds. 1982. An ecological characterization of South Carolina wetland impoundments. SC Mar. Resour. Cent. Tech. Rep. 51. SC Wildl. & Mar. Resour. Dept. Columbia, SC. 132 pp.
[91] Tiner, R. W., Jr. 1977. An inventory of South Carolina's coastal marshes. SC Mar. Resour. Cent. Tech. Rep. 23. SC Wildl. & Mar. Resour. Dept. Columbia, SC. 33 pp.
[92] Gordon et. al. 1989.
[93] Williams, R. K. 1987. Construction, maintenance and water control structures of tidal impoundments in South Carolina. Pages 139-166 *in*: W. R. Whitman and W. H. Meredith. eds. Waterfowl and Wetlands Symposium: Proc .

elevation of managed tidal wetland embankments typically is only slightly higher than the flooded water level of the interior managed wetlands, rising sea level poses a significant threat to their existence, and therefore the sustainability of these habitats for the benefit of migratory waterfowl and other managed tidal wetland species.

Equally important to the management of these wetlands is the salinity of the water used to facilitate water manipulations. At Samworth and Donnelley, freshwater has been the norm and the vegetation communities within the wetlands do not tolerate significant salinity. Even at Yawkey and Santee Coastal Reserve where embankments front on the ocean, relatively low-salinity riverine water has been available for water management purposes. Wetland management scenarios for these wetlands target a range of moderate salinities. As sea level rises and saltwater travels farther inland, fresh water near or at the coast will not occur. Saltwater management strategies will shift to hyper saline; brackish water management strategies will shift to saline; and freshwater management strategies will shift to brackish. These shifting salinity profiles will require DNR to adapt in order to effectively manage wetlands located directly on the coast.

3.1.1.10 DNR Response and Recommendations

Care must be given to ensure current regulatory mechanisms continue to protect this special kind of wetland as well as all other wetlands. Equally important is the need to be certain that the wetland protection regulations embrace an adaptive approach, when necessary, to benefit society and continue to protect all natural resource wetland attributes.

DNR should routinely monitor and maintain dikes, monitor water levels and salinities within and outside the wetlands. Embankments should be raised as needed and water control structures should be maintained and replaced as required. Adaptive relocation of water control structures may be necessary in order to adjust to changing riverine salinity profiles. Adaptive management of these wetlands, based upon water levels and salinities, is critical. Inland expansion or replacement of managed wetlands, by retreat, should be considered as properties become available.

3.1.2 Potential Effects Related to Changes in Water

3.1.2.1 Water Quantity

Water-supply issues are becoming increasingly critical.[94] With more demands on all water resources, it is essential to develop a comprehensive statewide conservation policy that balances human and natural resource needs. Without detailed information about capacity, long-term trends and their relation to the climate and the water budget,

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Symp. On Waterfowl and Wetland Manage. In the Coastal Zone of the Atlantic Flyway. Delaware Dept. of Natural Resour. and Environ. Control. Dover, DE. 522 pp.

[94] Bates, B. C., Z. W. Kundzewicz, S. Wu and J. P. Palutikof, *eds.* 2008: Climate change and water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp. http://www.ipcc.ch/pdf/technical-papers/climate-change-water-en.pdf. Last accessed July 2010.

an efficient and effective water plan will be difficult to implement. Water issues involve both surface and ground waters and include a myriad of factors that must be considered including availability, quality, recharge areas, source-area protection and storage. The primary interest is in fresh water, but at times salt water is an issue, in particular salt-water intrusion into coastal drinking-water wells as well as salt water moving up stream systems from estuaries.[95]

Surface water is monitored primarily by the United States Geological Survey (USGS), but additional information in critical areas would be helpful. Stream gauges provide water quantity information and also are used to monitor flood conditions and issue flood alerts by other agencies. At present, the ground-water monitoring system does not sufficiently cover the state, and a detailed, county-based ground-water monitoring program is needed to determine the availability and sustainability of ground water.

3.1.2.2 DNR Response and Recommendations

An effective policy for water management begins with a fundamental understanding of the behavior and processes that govern water movement and storage. Therefore, the most significant step to improve the understanding of South Carolina water supply is to increase monitoring capability of both surface- and ground-water sources, establish baseline measures of in-stream flow, better understand recharge and define recharge areas, develop databases to compile accumulated results and provide reliable information to assist in management decisions. Accurate assessment of ground-water availability can come only from long-term monitoring and a thorough understanding of the geologic architecture of the aquifers and their confining layers. This type of detailed work includes stratigraphic, subsurface geologic mapping and hydrogeologic studies. Results of these studies and others would reside in an integrated geologic, geophysical and hydrologic database that would benefit not only DNR, but all groups interested in surface- and ground-water issues.

Comprehensive basin-wide water planning should be done for each of the sub-basins in the state. These plans should include a detailed assessment of our ground- and surface-water resources, an assessment of ground- and surface-water use by water-use category, a water-demand analysis for each of the water-use categories, and a comprehensive water plan incorporating water-supply and water-demand management strategies to meet future demands and sustain the resource.

River-basin hydrologic models are needed for each of the sub-basins in South Carolina to predict where and when water shortages will occur and to evaluate the effects that changes in temperature and precipitation will have on surface-water supply. Ground-water flow models are needed in the coastal plain to predict the effects that withdrawals will have on aquifers. These models can be used to evaluate the effects that changes in precipitation and ground-water recharge rates have on our water supply.

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[95] Ranjan, S.P., Kazama, S. and Sawamoto, M. 2006. Effects of climate and land use changes on groundwater resources in coastal aquifers, J. Environ. Manage. 80(1):25-35.

A monitoring network is needed to study interactions between shallow ground water and surface water. The network could also be used to assess antecedent drought and flood conditions, and could be used as a barometer of drought conditions. This network could assist in understanding the relationships between base flow, ground-water levels and changes in precipitation.

3.1.2.3 Water Quality

In addition to affecting water quantity, climate change also will affect water quality.[96] Although DNR does not regulate water quality, the nature of how contaminants enter the water system is a direct function of the physical condition of the environment, including subsurface geology and land-use practices. The LWC can provide important technological and educational assistance in these areas.

3.1.2.4 DNR Response and Recommendations

Support is needed to adequately investigate of the state's subsurface geology. Prior knowledge of subsurface geology is important when planning for industry and development. The impact of accidental spills and remediation of hazardous-waste contamination can be reduced with proper planning. The availability of water, or lack thereof, is highly influenced in parts of the state by subsurface geology. The potential for geologic hazards, fault zones, also needs to be clearly defined. A comprehensive drilling program will help to establish the subsurface framework that influences ground water flow as well as earthquakes.

An expanded surface-water monitoring system also is needed. Monitoring should include water quality parameters such as water temperature, dissolved oxygen, pH, salinity and fecal coliforms. When combined with stream-flow data, this information can yield important information relative to how drought and flooding events impact water quality. These data could be used to augment the South Carolina Department of Health and Environmental Control (DHEC) monitoring system and to provide technical assistance to local governments and other stakeholders involved in land use planning.

A ground-water monitoring network along the coast should be established to measure salt-water intrusion. Strategically located wells in each aquifer should be continuously monitored for water level, temperature and specific conductance.

3.1.2.5 Potential Effects of Changes in Rainfall and Riverine Flow

Estuarine systems are among the most productive ecosystems on Earth and may be among the most sensitive to impacts of climate change as a result of changes in sea level and variation in rainfall that may shift salinity profiles and changes in biotic

[96] IPCC. 2007.

composition.[97] Shifts in salinity profiles in the estuarine system will depend entirely upon freshwater input and rainfall.[98] The projections for rainfall in South Carolina under a warming climate are unknown and require DNR to plan for a range of contingencies. The past decade has been dominated by drought conditions with accompanying shifts in the distribution of species within estuaries. Changes in biotic composition and the prevalence and seasonal distribution of diseased organisms must be expected, but little data exist to predict possible ramifications.

Salinity profiles in estuaries are expected to change as a result of both sea-level rise and changes in precipitation patterns. The former will shift the salinity regimes up estuaries; however the impact of the latter is unknown, as current models do not provide a clear direction to anticipated rainfall in South Carolina over the next few decades.[99] While estuarine species are renowned for their ability to tolerate salinity shifts over a tidal cycle, many have optimal ranges and move in the system according to prevailing conditions.

The worst scenario for sea-level rise could result in a landward shift in salinity resulting from sea-level rise accompanied by drought. This scenario would compress the available habitat, due in part to coastal development, likely resulting in reduced salt-marsh habitat in the optimal salinity ranges. Reduction of the spatial area covered by the salt marsh would reduce abundance and reproduction of estuarine species, as well as affect the entire ecosystem.

Another apparent consequence of extended droughts is drying out and dieback of saltwater marshes. The severe drought in 1999-2002 is thought primarily to have been responsible for salt marsh diebacks along the East Coast and Gulf of Mexico.[100] Studies in the Gulf of Mexico suggest that the drought caused low pH levels which resulted in greater bioavailability of metals which may have been responsible for *Spartina* mortality. On the South Carolina coast, both marsh meadows and marsh fringing tidal creek channels died in 2002.[101] It also is possible that low ground water levels resulting from drought may be related to salt marsh die offs. Salt marsh dieback has obvious implications including a reduction in primary productivity and increased vulnerability to predators of juvenile fishes and invertebrates.[102]

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[97] Michener, W., E. Blood, K. Bildstein, M. Brinson, and L. Gardner. 1997. Climate change, hurricanes and tropical storms and rising sea level in coastal wetlands. Ecological Applications. 7(3):770-801.

[98] Meynecke J., S. Lee, N. Duke andJ. Warnken. 2006. Effect of rainfall as a component of climate change on estuarine fish production in Queensland, Australia. Estuarine, Coastal and Shelf Sci. 69:491-504

[99] IPCC. 2007.

[100] Alber, M., E. Swenson, S. Adamowicz and I. Mendelssohn. 2008. Salt Marsh Dieback: An overview of recent events in the US. Estuarine, Coastal and Shelf Science. 80:201-211.

[101] D. Whitaker, personal observation. Dec 2002.

[102] Minelo, T. and R. Zimmerman. 1985. Differential selection for vegetative structure between juvenile brown shrimp (*Penaeus aztecus*) and white shrimp (*Peneus setiferus*), and implications for predator–prey relationships. Estuarine Coastal Shelf Sci. 20:707–716.

3.1.2.6 DNR Response and Recommendations

Field studies are needed to clearly document the effect and consequences that drought has on the salt marsh and its sensitive ecosystems. These studies would focus on determining the causes of salt marsh dieback and its impacts on primary and secondary productivity.

Accompanying hydrological studies are needed to determine the ambient conditions of coastal ground water and how ground-water levels and water chemistry are influenced by tidal fluctuations, sea-level change and drought. Field-based studies also are needed on the potential ecological and physiological impacts on mollusks, crustaceans and fish resulting from shifting salinity profiles and ocean acidification. Other studies of the migration and dispersal of estuarine species, especially those near the southern limits of their range, are needed.

Support is needed to develop predictive models that project expected sea-level rise, accompanied by a broad range of rainfall and hydrological scenarios. GIS mapping and mathematical modeling of estuarine water salinities as related to changes in river flow and local drought also are needed. This information would define affected marine species that will be forced farther inland than present or whose populations could be negatively impacted by reduced optimal nursery habitat. Mitigation plans could be established and implemented once information is available.

3.1.3 Potential Effects of Temperature Rise

3.1.3.1 Temporal and Spatial Shifts in Habitat and Life Histories

Shifting climate can cause changes in the spatial distribution of habitat and/or temporal aspects of life history. Shifts in habitat can occur in patches across the landscape, or the geographic range of species can shift. Temporal shifts in life history of species also are likely to occur in response to warmer or cooler temperatures, changes in precipitation, changes in vegetation or shifting seasons. For example, species' reproductive cycles can occur earlier or later in the year (budding has been observed to be occurring earlier for some plant species), become shorter or longer in duration, or occur earlier or later in age. Species at the edges of their range or in marginal habitats need to be able to migrate or disperse to adjust to changing habitat conditions.

Striped bass (*Morone saxatilis*) occurring in lakes that thermally stratify, such as lakes Murray and Thurmond, may experience increased incidence of mortality due to the vertical compression of oxygenated habitat. This could lead to population shifts away from striped bass toward species more tolerant of habitat compression such as hybrid striped bass (*Morone saxatilis* x *Morone chrysops*).[103]

[103] Brandt, S. B.; Gerken, M.; Hartman, K. J.; Demers, E. 2009. Effects of hypoxia on food consumption and growth of juvenile striped bass (*Morone saxatilis*). J. Exp. Marine Biol. Ecol. 381: S143-S149 .

3.1.3.2 DNR Response and Recommendations

A comprehensive strategy and long-term monitoring program is needed to assess spatial and temporal impacts to organisms, particularly for sensitive, rare or vulnerable species. Knowledge of life history and range for species is needed to develop effective management strategies to protect wildlife and freshwater and marine fishes and their habitat.

3.1.3.3 Population and Ecosystem Effects

Changes in climatic conditions have been linked with ecosystem-wide regime shifts resulting in major changes in species diversity and interactions at all trophic levels.[104] Climate change also has been associated with a northward shift in the distribution of many marine fish species across the Northern Atlantic, the Northwest Pacific and the Bering Sea.[105] [106] The evidence supporting climate-related shifts in distribution and abundance in the southeastern United States is limited since the issue has not been explicitly examined. The potential effects are profound, especially if economically important species are impacted, or if unexpected shifts occur that affect the biodiversity, stability or resilience of ecosystems.

Temperature has a direct effect on the physiology and survival of aquatic species. For example, temperature directly affects their physical growth and maturity, since the majority of aquatic species is poikilotherms, or cold blooded, and has metabolic rates that fluctuate with environmental temperature. Such changes can affect the rate of energy transfer between trophic levels, influence productivity and the function of the marine ecosystem as a whole. Survival can be directly affected by a species' upper and lower temperature tolerances. Overwinter mortality caused by freezes can have major impacts on the abundance of some species, such as spotted seatrout.[107] Conversely, other species utilizing habitats near their thermal maximum, for instance striped bass (*Morone saxatilis*) utilizing coastal waters, may be negatively impacted by high temperatures in the summer.

The abundance and annual commercial landings of brown shrimp (*Farfantepenaeus aztecus)* appear to have declined steadily in South Carolina over the last 2 decades concurrent with increasingly warm winters. Although no cause and effect has been definitively identified, it is hypothesized that the species' recruitment mechanism requires relatively cold winters. On the other hand, the white shrimp (*Litopenaeus*

[104] Beaugrand G. 2009. Decadal changes in climate and ecosystems in the North Atlantic Ocean and adjacent seas. Deep Sea Research Part II: Topical Studies in Oceanography. 56:656-673.
[105] Grebmeier, J., J. Overland, S. Moore, E. Farley, E. Carmack, L. Cooper, K. Frey, J. Helle, F. McLaughlin and S. McNutt. 2006: A major ecosystem shift in the northern Bering Sea. Science, 311(5766):1461-1464.
[106] ter Hofstede, R., J. Hiddink, and A. Rijnsdorp. 2010. Regional warming changes fish species richness in the eastern North Atlantic Ocean. Mar. Ecol. Prog. Serv. 414:1-9.
[107] South Carolina Department of Natural Resources. 2007. State of South Carolina's coastal resources: Spotted seatrout. http://www.dnr.sc.gov/marine/mrri/pubs/yr2007/seatrout07.pdf. Last accessed Dec 2010.

setiferus), is a subtropical species that may benefit from warmer winters and may expand its range farther north.[108]

Shifting water temperatures in the nearshore and shelf-break can lead to a shift in the distribution of both larval and adult fish. Increasing water temperatures could lead to shifts in areas of maximal abundance and overall species range for species such as red snapper (*Lutjanus campechanus*), red grouper (*Epinephelus morio*), gag (*Mycteroperca microlepis*) and scamp (*Mycteroperca phenax*). Anecdotal evidence suggests that shifts in some species' ranges may have occurred already off South Carolina.[109]

Strong year classes of Atlantic croaker (*Micropogonias undulatus*) populations along the mid-Atlantic coast have been positively related to warmer-than-normal winters.[110] Presumably, a higher frequency of warmer winters could modify the relative abundance for other important species and could result in significant shifting of ecological relationships including trophic structure, food webs and others. A long-term study in Narragansett Bay has documented a progressive shift in the marine community from vertebrates to invertebrates and, especially since 1980, from benthic to pelagic species.[111] Populations of small, short-lived forage species of fish, in particular, can change rapidly in response to climate variation, which can affect the growth and survival of other fish, mammals[112] and birds[113] that consume them.

Some diadromous species are near the southern end of their ranges in South Carolina. Many of these species already are stressed by summer conditions including high temperatures and, in some cases, low dissolved oxygen and anthropogenic impacts.[114] Finfish examples include the shortnose sturgeon (*Acipenser brevirostrum*), federally listed as endangered, and the Atlantic sturgeon (*Acipenser oxyrinchus*), a species of concern that was recently petitioned for listing as endangered. Both of these fish previously were of great economic, nutritional and cultural value to the state.[115] Climate change could exacerbate management problems for these and other species including shad species and river herring (*Alosa spp.*), or even in some cases, limit or eliminate their occurrence in South Carolina. Recruitment failure may occur in severe drought conditions as a consequence of dewatering of gravel bars and absence of the

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[108] D. Whitaker, personal observation.

[109] J. Ballenger, MRRI, DNR. Personal communication

[110] J. Hare and K. Able. 2007. Mechanistic links between climate and fisheries along the east coast of the United States: explaining population outbursts of Atlantic croaker (Micropogonias undulatus) Fish. Oceanogr. 16(1):31–45,

[111] Collie, J., A. Wood, and P. Jeffries. 2008 Long-term shifts in the species composition of a coastal fish community Can. J. Fish. Aquat. Sci. 65:1352–1365.

[112] McLeod, et al. 2007. Linking sand eel consumption and the likelihood of starvation in harbour porpoises in the Scottish North Sea: could climate change mean more starving porpoises? Biol. Lett. 3:185-188.

[113] Frederiksen, et al. 2004. Scale-dependent climate signals drive breeding phenology of three seabird species. Global Change Biol, 10:1214-1221.

[114] Jenkins, W.E., T.I.J. Smith, L.D. Heyward and D. M. Knott. 1995. Tolerance of shortnose sturgeon, *Acipenser brevirostrum*, juveniles to different salinity and dissolved oxygen concentrations. Proc. Southeast. Assoc. Fish and Wildl. Agencies. 47:476-484.

[115] Leland, J. 1968. A survey of the sturgeon fishery of South Carolina. Contribution from Bears Bluff Laboratories. No. 41. 27 pp.

seasonally elevated flows which serve as a cue for spawning migration. Results of preliminary modeling investigations suggest that local extinction can occur rapidly.[116]

Freshwater fish species also are likely to be affected by changes in temperature regimes. Eastern brook trout (*Salvelinus fontinalis*) are the most sensitive to temperature of the 3 trout species that occur in South Carolina. They require colder water than rainbow (*Oncorhynchus mykiss*) and brown (*Salmo trutta*) trout. DNR has monitored temperatures in brook trout streams on the Sumter National Forest and Jocassee Gorges streams. Currently, maximum summer temperatures in South Carolina brook trout streams routinely reach 68-70°F (20-21°C) during the hottest summer periods. Brook trout typically do not occur in streams where maximum temperatures exceed 70°F (21°C). Any increase in stream temperature as a result of climate change likely would result in the loss of the species in South Carolina.

Smallmouth bass (*Micropterus dolomieu*) are a popular temperature-dependant coolwater sport fish that are managed in a number of South Carolina waters. For example, if waters were to warm in the Broad River, this recreationally valuable fishery could become jeopardized.

No studies of the response of nongame fishes to projected climate change in South Carolina or the southeastern United States have been published, but research elsewhere has predicted decline in distribution of cool and cold-water fishes.[117] In South Carolina, likelihood of extirpation from the state is high for the suite of fishes that are endemic to the southern Appalachian highlands, as these populations which are restricted to the upper reaches of the Savannah and Saluda drainages are relics from historic stream capture from the Tennessee River system. It also is possible that other upland-endemic species noted in the CWCS as sensitive to environmental change could decline in abundance and distribution with climate change.

Even if the overall distribution of fish species or their center of abundances is unchanged due to warming water temperatures, climatic changes could affect fish populations in other ways. Blue catfish (*Ictalurus furcatus*) are a nongame species that was introduced to the state's waters decades ago. No adverse effects to other aquatic species have been documented as a result of this introduction, and a popular fishery has developed for blue catfish. However, increased average water temperatures could result in increased competition between blue catfish and other species for spawning resources. Blue catfish spawn in temperatures ranging from 70-84°F (21-29°C). A typical spawning could shift from May to April could occur if temperatures rise. Native catfish, which usually do not compete for resources with blue catfish, may compete for spawning sites. This competition could be more pronounced if climate change altered seasonal durations, creating a shorter spring and a more prolonged summer.

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[116] J. Hightower, USGS, Raleigh, NC. Personal communication.

[117] Lyons, J, J.S. Stewart and M. Mitro. 2010. Predicted effects of climate warming on the distribution of 50 stream fishes in Wisconsin, U.S.A. Journal of Fish Biology 77: 1867-1898.

Additionally, climatic changes could alter the timing of the spring phytoplankton blooms – affecting zooplankton populations that many larval and juvenile fish species depend on as prey during this critical period of development. Conversely, climatic changes could directly affect the maturation of fishes, causing a shift in the spawning season. In any case, this could lead to a mismatch in the temporal period for which prey are available to larval and juvenile fish species in any given year, leading to more sporadic recruitment events and a higher probability of recruitment failure in any given year. This effect is often referred to as the Cushing match-mismatch hypothesis.[118]

Evidence is emerging that variations in annual oceanographic events affect the phytoplankton distribution of productivity.[119] For example, studies in other areas indicate that the intensity and timing of seasonal upwelling events have shifted compared to previous decades. This can have major effects on coastal ecosystems and may change the species composition of phytoplankton.[120] For example, the relative proportion of dinoflagellates, which tend to prefer warmer and more stratified water columns, may increase with respect to diatoms.[121]

It is unknown if a longer growing season would affect South Carolina oysters (*Crassostrea virginica*), but it might be due to effects on species composition and abundance of phytoplankton.

Seasonal inshore-offshore and latitudinal distributions, timing of migration and duration of nesting season of loggerhead sea turtles appear to be greatly influenced by water temperature.[122] Satellite-tagged juvenile loggerhead sea turtles have been shown to demonstrate inshore-offshore movement coincidental with water temperatures of 17°C.[123] It also has been demonstrated that warmer sea-surface temperatures in at least some locations lead to earlier onset and longer duration of nesting seasons.[124] It is not known to what degree extended warm weather seasons may alter these life history dynamics, and what the consequences of these environmental changes could have on the recovery of this threatened species. Additionally, sea turtle sex ratios are known to be determined by incubation temperatures in the nest, with warmer

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[118] Cushing, D.H. 1990. Plankton production and year-class strength in fish-populations – an update of the match mismatch hypothesis. Advances in Marine Biology 26:249-293.

[119] Hays, G., A. Richardson and C. Robinson. 2005. Climate change and marine plankton. Trends in Ecology and Evolution. 20(6):337-344.

[120] Barth, J. B. Menge, J. Lubchenco, F. Chan, J. Bane, A. Kirincich, M. McManus, K. Nielsen, S. Pierce and L. Washburn. 2007. Delayed upwelling alters nearshore coastal ocean ecosystems in the northern California current. Proc. of the Nat. Acad. of Sci. 104(10):3719-3724.

[121] Monterey Bay Aquarium Research Institute. 2006. Seeing the Future in the Stratified Sea. 2006 Annual Rept. http://www.mbari.org/news/publications/ar/chapters/06_timeseries.pdf. Last accessed Dec 2010.

[122] Bjorndal, K.A., A.B. Meylan and B.J. Turner. 1983. Sea turtle nesting at Melbourne Beach, Florida, I. Size, growth and reproductive biology. Biological Conservation, 26:65-77.

[123] Arendt, M., J. Byrd, A. Segars, P. Maier, J. Schwenter, D. Burgess, J. Boynton, D. Whitaker, L. Liguori, L. Parker, D. Owens and G. Blanvillain. 2009. Examination of local movement and migratory behavior of sea turtles during spring and summer along the Atlantic coast off the southeastern United States. SC DNR, Univ. GA and College of Charleston, Final Report to NOAA Fisheries, Contract Number NA03NMF4720281, 177 pp.

[124] Hawkes, L.A., A.C. Broderick, M.H. Godfrey and B.J. Godley. 2007. Investigating the potential impacts of climate change on a marine turtle population. Global Change Biology, 13(5): 923-932.

temperatures resulting in sex ratios skewed to females.[125] It is conceivable that climate change could cause additional bias in sea turtle sex ratios, and males might become the limiting resource. In a worst-case scenario, a warming local climate could lead to the elimination of male offspring production altogether.[126]

3.1.3.4 DNR Response and Recommendations

Continuation of long-term surveys and archiving, integrating and analyzing the data they produce are essential to understanding climate-related impacts on the state's wildlife and freshwater and marine fisheries resources.

Abundant data exist to explore climate-related issues in databases compiled by MRD, other DNR sections and other organizations including NOAA and the University of South Carolina Baruch Marine Research Institute (BMRI) but funds for analyses are lacking. The MRD databases archive information from numerous ongoing, long-term (10-30 year) biological surveys that cover a variety of key habitats, ranging from small estuarine creeks to offshore deep waters. Examples include an electrofishing survey of upper estuarine habitats, a trammel net survey of lower estuarine marshfront, an estuarine crustacean trawl survey, a coastal trawl survey, a coastal shark and adult red drum longline survey and an offshore live bottom survey. These surveys often complement one another because many species spend different parts of their life cycle in different habitats. Two of the surveys, which are federal programs administered and conducted by MRD staff, cover the entire South Atlantic Bight (SAB) from North Carolina to Florida. They include the Southeast Area Monitoring and Assessment Program (SEAMAP), which began a shallow water trawl survey of the near-coastal SAB in 1986, and the Marine Resources Monitoring, Assessment and Prediction (MARMAP) program, which began research further offshore in 1973 and primarily covers live bottom habitat.

In addition to the various fishery-independent surveys mentioned above, the OFM compiles fishery-dependent databases that record harvest rates of recreationally and commercially important species such as shrimps, crabs, oysters and fish.

Continued support of these long-term surveys is critical for understanding climate-related changes in the marine system, and for predicting potential future scenarios for South Carolina's marine resources. The value of the surveys derives from the time periods covered and the use of standardized collection methodology enabling meaningful, comparable data across years. Support for the collection of additional important biotic and abiotic data, such as fish and crustacean community structure and densities, life history information, temperature and salinity is essential. Existing programs currently provide data for regional stock assessments, but lack resources for critical analyses and modeling of existing data to support climate change studies.

[125] Mrosovsky, N, and C.L. Yntema. 1980. Temperature dependence of sexual differentiation in sea turtles: implications for conservation practices. Biological Conservation 18:271-28

[126] Blanvillain, G., L. Wood, A. Meylan. and P. Meylan. 2008. Sex ratio prediction of juvenile hawksbill sea turtles from South Florida, USA. Herpetological Conservation and Biology 3(1):21-27.

In order to assess the impacts of climate change on freshwater fisheries, a model simulation is needed for various scenarios of climate change using stream assessment data recently collected across the state to provide an objective evaluation of risk to native upland fish species.

Monitoring of penaeid shrimp, crab, fish and oyster populations should continue with fishery-dependent and fishery-independent methods. Efforts should be made to determine relationships between climate change and population dynamics of important species, for instance the impact of warmer winters on brown shrimp recruitment.

Data from other sources are also available, such as the long-term monitoring projects conducted by the BMRI. The integration of data across surveys, across DNR sections and across other research institutes would be a powerful method of detecting long-term biological trends associated with climate change. To facilitate this, it would be useful to compile an easily accessible list of all data sources within the DNR as a whole to integrate marine, freshwater and climate data sources, as well as other organizations within the state that collect long-term data. Comparison of these data with information available from other regions along the Atlantic and Gulf coasts would be useful in order to detect regional patterns.

There is a need to compile and analyze water temperature records from multiple locations to determine if temperatures have increased significantly in the last decade along the Gulf of Mexico and South Atlantic Coast as related to nearshore loggerhead sea turtle foraging grounds. Also needed is repeated examination of the sex ratios in loggerhead sea turtle nests with respect to spatial and temporal variability. At-sea monitoring of sea turtles with trawls should be continued to document overall population trends of juveniles and adults.

Agencies and local communities should continue education and eradication campaigns to eliminate beach vitex, an invasive plant that restricts nest building by sea turtles.

Populations of diadromous species should be evaluated in all major coastal rivers to estimate populations and monitor trends.

3.1.3.5 Harmful algal blooms (HABs)

HABs are caused by certain species of microscopic photosynthetic algae (phytoplankton). They cause a wide range of detrimental effects that are species-specific. Examples include shading and destruction of estuarine grass habitat, shellfish poisoning and toxin production that can bioaccumulate up the food chain and induce sickness and death in wildlife and humans. There has been an increase in reported HAB events over recent decades,[127] partly because of improved monitoring, but also

[127] Anderson, D.M. 2004. The growing problem of harmful algae: Tiny plants pose potent threat to those who live in and eat from the sea. Woods Hole Oceanographic Institution. http://www.whoi.edu/page.do?pid=11913&tid=282&cid=2483. Last accessed Jan 2011.

because of increased aquatic nutrient loading from run-off, alteration in land use patterns and the introduction of exotic HAB species. Climate change may further affect the timing and intensity of HAB events, but the overall relationships among climate change and other factors affecting the HAB prevalence remain unclear. For example, blooms of toxic cyanobacteria and raphidophytes are common in South Carolina. These blooms can cause mass fish kills and often are associated with increased levels of certain nutrients, particularly nitrogen;[128] [129] however, the timing and duration of blooms may be augmented by climate change.

3.1.3.6 DNR Response and Recommendations

The South Carolina Algal Ecology Laboratory has been jointly operated by USC and DNR over the last decade. Additional collaborations exist with the National Ocean Services, Charleston Laboratory. The monitoring and research performed by these collaborative efforts should be encouraged. Examples of relevant questions concerning HABs and climate change include:

1. Does climate change lead to longer summer growing seasons, and if so, then how would HAB taxa that tend to be more responsive to warmer temperatures respond? How might these co-vary with land use patterns?
2. Would harmful blooms simply persist for longer timeframes under predicted climate change scenarios?
3. Or, would phytoplankton blooms eventually exhaust their supply of nutrients, die off, and subsequent microbial respirations adversely affect water oxygen levels, thus inducing hypoxia?

3.1.3.7 Hypoxia and Dead Zones

Increasing temperatures can reduce oxygen levels in coastal waters through a variety of mechanisms such as a decrease in the solubility of oxygen, an increase in productivity and stratification of the water column. Hypoxia-related events have been well-documented in other coastal regions after, for example, extended phytoplankton blooms including in the Gulf of Mexico and Long Island Sound in New York.[130] Hypoxia often is related to increased nutrient run-off coupled with a stratified water column. These combined processes often promote proliferation of phytoplankton biomass, including that of HAB species. Cessation of blooms is typically coupled with increased oxygen consumption by bacteria, and in extreme cases, this oxygen consumption causes hypoxic conditions or dead zones, where oxygen concentrations fall below levels supporting life. These hypoxic regions impact benthic or demersal species and can result in considerable losses to fisheries. The incidences of dead zones are increasing worldwide and are believed to be, in part, a result of increasing global temperatures

[128] Chorus I, Bartram J (1999) Toxic cyanobacteria in water. World Health Organization, London.
[129] Downing TG, Meyer C, Gehringer MM, Venter M (2005) Microcystin content of *Microcystis aeruginosa* is modulated by nitrogen uptake rate relative to specific growth rate or carbon fixation rate. Environ Toxicol 20:257-262
[130] Diaz, R.J. and R. Rosenberg. 2008. Marine ecosystems spreading dead zones and consequences for marine ecosystems. Science. 321:926-929.

promoting greater water stratification.[131] The phenomenon can be exacerbated by nutrient-laden freshwater runoff related to increasing impervious surfaces from coastal development and changes in rainfall patterns. Numerous dead zone events have occurred in South Carolina during the last 2 decades, but most have been confined to small estuarine creeks and were of short duration. In 2004 and in 2009, relatively large events occurred in coastal waters just off Horry County in Long Bay.[132] Preliminary studies indicate these events were caused by persistent southwest winds resulting in upwelling near the coast, thence causing the unusual effect of trapping nutrient-laden water near the beaches, leading to hypoxia. Climate-related changes in ocean and wind circulation patterns could result in a greater frequency of coastal hypoxia. [133]

3.1.3.8 DNR Response and Recommendations

The relationship between climate change, land use and phytoplankton bloom timing and intensity is virtually unstudied for coastal South Carolina, but should be an important focus of future research. Agencies and universities should continue to form partnerships to monitor coastal hypoxia. Permanent nearshore monitoring stations strategically located along the coast should be maintained to monitor physical and chemical aspects of coastal waters. Efforts should be made to develop mathematical models that can explain hypoxia events, including the oceanographic conditions that give rise to them. Anthropogenic causes of hypoxia should be addressed and corrected where possible.

3.1.3.9 Potential Effects of Ocean Acidification

Increasing ocean acidification apparently related to increasing CO_2 levels in the Earth's atmosphere raises concerns about the future of reef-building corals and other species that incorporate calcium carbonate into their skeletons including mollusks, crustaceans and some plankton.[134] While South Carolina does not have shallow-water coral reefs, the impact of ocean acidification on oysters and other species is of concern. It is expected that ocean pH will fall to about 7.8 over the next 300 years and this is within the range known to impact oyster growth. However, pH in estuaries typically ranges between 7.0-7.9, with the lower values known to impact a variety of physiological and

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[131] Kelling, R, and H. Garcia. 2002. The change in oceanic O2 inventory associated with recent global warming. Proc. Nat. Acad. Sci. 99(12):7848-7853.

[132] Sanger, D. , D. Hernandez, S. Libes, G. Voulgaris, B. Davis, E. Smith, R. Shuford, D. Porter, E. Koepfler and J.H. Bennett. 2010. A case history of the science and management collaboration in understanding hypoxia events in Long Bay, South Carolina, USA. J. Environmental Manage. 46:340-350.

[133] Gregg, R.M. L.J. Hansen, K.M. Feifel, J.L. Hitt, J. M. Kershner, A.Score, and J. R. Hoffman The State of Marine and Coastal Adaptation in North America: A Synthesis of Emerging Ideas. Eco. Adapt. Bainbridge Island, WA. http://www.cakex.org/sites/default/files/EcoAdapt%20Synthesis%20Report%20January%202011.pdf. Last accessed May 2011.

[134] Orr, J.,, V. Fabry, O. Aumont, L. Bopp, S. Doney, R. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joos, R. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R. Najjar, G. Plattner, K. Rodgers, C. Sabine, J. Sarmiento, R. Schlitzer, R. D. Slater, I. Totterdell, M. Weirig, Y. Yamanaka and A. Yool. 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature. 437:681-686.

immune functions in oysters.[135] Further deceases in pH could result from increasing ocean acidification, acid rain and increasing development in the coast zone. The effects of low pH are amplified at higher temperatures. Whether the expected increases in ocean acidity, atmospheric CO_2 and temperature pose serious threats to oysters and other estuarine species is difficult to assess as the issue has not been well studied. Similar concerns exist for many crustaceans, as the molting process involves calcium demineralization and re-mineralization of the exoskeleton and this is influenced by both internal pH as well as external pH. Increased acidification also could impact phytoplankton bloom dynamics and regional primary productivity.

3.1.3.10 DNR Response and Recommendations

Agency and university researchers should cooperatively monitor pH in coastal waters. Support is needed for research on the potential ecological and physiological impacts of shifting salinity profiles and ocean acidification on mollusks, crustaceans and fishes.

3.1.4 Potential Effects Related to Changes in Terrestrial and Aquatic Habitats

3.1.4.1 Habitat Fragmentation

Habitat decline, shifting climate regime, increasing development, particularly in coastal areas, and rising sea level represent constraints and barriers to dispersal and migration of fish, wildlife and plant species.[136] Maintaining migratory corridors is essential for the ability of wildlife and fishes to find suitable habitat and for population maintenance. Over the past several decades, habitats within South Carolina have become increasingly fragmented. Natural areas have been developed and roads have been created or widened throughout much of the state. This development has disrupted traditional corridors and resulted in pockets of wildlife habitat that are isolated from one another. Dams and other barriers have fragmented entire river systems and impede migration of diadromous and freshwater fish as well as many invertebrate species. As climate changes, further habitat fragmentation will restrict movement of animals, limiting or preventing the critical ability to migrate to more favorable habitats.

3.1.4.2 DNR Response and Recommendations

The South Carolina Heritage Trust Program was created in 1976 to help stem the tide of habitat loss by protecting critical endangered species sites through acquisition and other means. Enabling legislation directed DNR, in concert with other state agencies, to set aside a portion of the state's rich natural and cultural heritage in a system of heritage preserves to be protected for the benefit of present and future generations (Sec. 51-17-20, 1976 *S.C. Code of Laws*).[137] Support for the Heritage Trust and other habitat

[135] Gazeau, F., C. Quiblier, J. Jansen, J.P. Gattuso, J. Middelburg and C Heip. 2007. Impact of elevated CO2 on shellfish calcification. Geophysical Research Lett. 34 :L07603, doi:10.1029/2006GL028554.
[136] P. Opdam and D. Wascher. 2003. Climate change meets habitat fragmentation: linking landscape and biogeographical scale levels in research and conservation. Biological Conservation 117:285–297. http://research.eeescience.utoledo.edu/lees/Teaching/EEES4760_07/Opdam.PDF Last accessed Sept 2010.
[137] http://www.scstatehouse.gov/code/statmast.htm. Last accessed Sept 2010.

protection programs is needed to identify, create and preserve important conservation corridors to allow migration and movement of affected species. In addition, the agency will need to investigate ways to partner with other agencies and non-governmental organizations to develop and maintain adequate migration corridors.

3.1.4.3 Loss and Alteration of Habitats

Temperature changes likely are to result in changes in vegetative structure of wildlife habitats throughout the state. In the event local temperatures warm, higher elevation habitats could suffer; cooling temperatures could affect lowcountry habitats. More rapid and extreme temperature fluctuations could stress populations and restrict thermal refugia. These changes could result in habitat loss and a change in both vegetative and animal community structure. Two examples of important freshwater fisheries at increased risk are trout (subfamily *Salmoninae*) and striped bass. Habitat loss not only affects the area in which the species can live, it also affects food availability and availability of suitable nesting/breeding areas. Impacts associated with temperature changes most likely will be greater in the higher elevations of the state.

Precipitation changes will affect both surface and groundwater levels and will result in impacts to both terrestrial and aquatic systems.[138] Wildlife depends on a variety of water sources within the state. All animals require water within their habitats, some more than others. Changes in wetland systems will affect many species of birds (particularly waterfowl), reptiles and amphibians that depend on these areas for foraging and breeding habitats. Isolated freshwater wetlands, small streams and seepage wetlands are critical to the survival of many of these species. Small wetlands and the species associated with them may be excellent indicators for the effects of climate change on larger systems.

Freshwater aquatic systems are susceptible to changes in precipitation. Streams, rivers, lakes and ponds are dependent upon both precipitation and groundwater recharge to maintain flow and water levels. Changes in surface and groundwater levels can affect the species assemblages and migration in freshwaters throughout the state.

3.1.4.4 DNR Response and Recommendations

There is the need to gather plant and animal baseline data for terrestrial and aquatic habitats and monitor the rate of change in both vegetative and animal community structures. The agency should use the information collected to determine appropriate management options in response to climate change and adapt management activities as climate changes occur in response to the changing habitat needs of wildlife and fish species. DNR should use these data to develop predictive models of the effects of temperature changes.

Monitoring the rate of water level and flow change in all surface waters and groundwater systems is vital to terrestrial as well as aquatic habitats. DNR should use the

[138] IPCC. 2007.

information collected to determine appropriate management options in response to climate change and adapt its management activities as climate changes occur in response to the evolving habitat needs of wildlife and fish species. The agency should use data collected to develop models that can assist in predicting water level and flow change and work with other entities to ensure adequate water levels and flow rates for wildlife and fish.

3.1.4.5 Habitat Impacts Related to New and Alternative Energy

As the nation strives to locate and utilize alternative, cleaner and more carbon-neutral sources of energy, it is important to understand that such sources may result in additional impacts to wildlife, fish and their habitats. Increased demand for biofuels can result in decreased wildlife habitat as forests and conservation areas are converted to production areas. Wind power, both on- and off-shore, can result in increased mortality to birds and bats. Hydropower can result in reduced flow in rivers and restrict movements of freshwater and diadromous fish as well as cause direct impacts through turbine impingement. Impacts to natural resources may be mitigated during planning, permitting and licensing for alternative energy projects.

3.1.4.6 DNR Response and Recommendations

The agency should work with all stakeholders including utilities, other agencies, NGOs, legislators, government planners and other experts as alternative energy sources are developed, licensed and brought on line to ensure natural resource needs are addressed during planning.

3.2 Potential Biological Effects Resulting from a Changing Climate

3.2.1 Species and Habitat Data

3.2.1.1 Insufficient Data for Species and Habitat

Although very detailed distribution and life history data exist for some harvestable species within the state and for a limited number of special status species (threatened and endangered species), these types of data are lacking for the majority of wildlife and freshwater fish. Without information about the distribution and abundance of species and their habitat requirements, reproductive abilities and longevity, it will be very difficult to understand and respond to impacts associated with climate change.

DNR has developed a plan to identify species of greatest conservation need in the state through its *South Carolina Comprehensive Wildlife Conservation Strategy* (CWCS) which includes recommendations to address threats to these species and their habitats.[139] A total of 1,240 species is identified in the CWCS, including marine species. Because these species currently are considered at risk, any additional impacts

[139] Kohlsaat, T., L. Quattro and J. Rinehart. 2005. South Carolina Comprehensive Wildlife Conservation Strategy. SC Dept. Nat. Resour. http://www.dnr.sc.gov/cwcs/index.html. Last accessed Sept 2010.

associated with climate change will exacerbate current threats; data needs identified for those species in the CWCS should be addressed as we manage for climate change.

In addition to those species identified in the CWCS, other wildlife and fish species are likely to experience impacts related to climate change. Habitat for local, migrating and wintering waterfowl, neotropical migrant birds, reptiles and amphibians as well as a number of freshwater fish species is particularly vulnerable to climate change impacts.

3.2.1.2 DNR Response and Recommendations

The agency should continue to collect baseline data for wildlife and fishes in South Carolina. Data collection projects should include abundance, distribution and life history studies. Data should be utilized to determine appropriate management options in response to climate change. Habitat management activities must be adaptive as climate changes occur in response to the changing needs of wildlife and fish species. DNR should use data collected to develop models that can assist in predicting species response to climate change.

3.2.1.3 Habitat Data and Characterization

As with information about wildlife and fish species in South Carolina, there is a lack of data concerning the historic and current condition of habitats. Without current or past baseline data, it will be very difficult to assess the vulnerability of habitats and to determine the rate of habitat loss. In addition to the need for baseline data, it will be critical to identify the climate change effects on wildlife and fish habitat.

3.2.1.4 DNR Response and Recommendations

DNR should collect baseline data on the condition of wildlife and fish habitat in South Carolina. This information should be used to determine appropriate management options in response to climate change. The agency should adjust management activities as climate changes occur in response to the changing habitat needs of wildlife and fish species. Data collected can be utilized to develop models that can assist in predicting habitat response to climate change.

3.2.2 Endangered, Threatened or Species of Concern

3.2.2.1 Declining Habitat for Endangered, Threatened or Species of Concern

Habitat loss is the most important factor contributing to species decline. Climate change may exacerbate habitat decline, particularly for rare or sensitive species such as amphibians. Nuisance and exotic species invasions, changes in plant and animal community structure and changes in abiotic factors such as hydrology, soil moisture and climate are areas of great concern relative to rare or sensitive species conservation.

3.2.2.2 DNR Response and Recommendations

DNR maintains and manages the South Carolina Rare, Threatened and Endangered Species Inventory. Much of the data in the Inventory is submitted to DNR by citizens and academic institutions, so data acquisition is driven by individual submissions rather than a comprehensive plan or strategy. Additional support for comprehensive and long-term monitoring of rare and sensitive plant and animal species is needed. This should involve development of a more modern inventory system with significant IT support. The current database should be screened and standardized with other systems in the region.

An improved monitoring strategy can provide vital data to guide conservation and habitat management activities. Again, there is opportunity to partner under the umbrella of existing and future conservation efforts. Potential conservation activities include translocation of species where appropriate, rare plant species propagation and identification and protection of important habitat. The management of natural resources will become increasingly difficult and complicated as climate change advances. The Conservation Section within the LWC can provide needed leadership and technical expertise to local, regional and statewide conservation and planning efforts.

3.2.3 Invasive Species

3.2.3.1 Potential for Introduction of Invasive Species

Increased temperatures, changes in rainfall and other environmental factors affected by climate shifts or change can create ideal conditions for proliferation of invasive plant and animal species, including parasites and pathogens. An increase in the number and diversity of native and non-indigenous invasive plant and animal species has been documented in South Carolina terrestrial, freshwater and marine habitats. Some of these species may have been released accidently or by well-meaning citizens, but others are likely migrating northward from more tropical climates as a result of warming temperatures. Regardless of the manner in which they have become established, these species already are impacting native animals and their habitats. As climate changes, an increasing number of exotic species likely will migrate to South Carolina. Habitats can be destroyed as resources are over-utilized. Invasive and non-indigenous species have the potential to outcompete native species for food and other resources.

Impacts of invasive species are second only to habitat loss for the significant decline and extirpation of both endangered and common species. The current environmental, economic and health costs of invasive species could exceed $138 billion per year in the United States, more than all other natural disasters combined. In 2006 alone, the United States spent $1.2 billion combating invasive species. That total does not even consider the numerous hours and dollars spent at regional, state and private levels to combat invasive species.[140]

[140] Pimental, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and economic costs associated with non-indigenous species in the United States. Biosci. 50(1):53-65.

Invasive species can completely overtake unique, sensitive and important habitats, such as those protected on lands dedicated as DNR Heritage Preserves, and out compete other established natives, forcing them into endangered, threatened or species of concern status. Stressed vegetation is vulnerable to attack by non-indigenous parasites and pathogens. The identification and acquisition of land for preserves often is based on the presence of unique native floral or faunal populations; however, if climate change alters local conditions in ways that allow invasive species to proliferate, the value of conservation lands as habitat for native species can become compromised.

Tilapia is a warmwater non-indigenous group of fish that extensively are stocked under permit in the state to control algae in private ponds. With few notable thermal refuges excluded, tilapia will die from cold stress in a typical South Carolina winter when water temperatures drop below 50°F (10°C). Historically, south coastal South Carolina water temperatures routinely drop to 45-50°F (7-10°C) during the winter. In the event that waters were to warm in the state, the potential for tilapia to overwinter is possible. Tilapia currently overwinters in Florida and has become an invasive species and a major management problem. If tilapia were to routinely overwinter in South Carolina it would result in direct competition with native and existing species for space, food, habitat and spawning areas, which could drastically alter natural fish communities.

The destruction that non-indigenous peacock bass (*Cichla* spp.) can cause to native fish communities is well documented.[141] In Florida, these fish currently are widespread, but, fortunately, these fish are very temperature dependant and do not typically survive in waters cooler than 60°F (16°C). Given current South Carolina winter low temperatures, tilapia is much more of an eminent threat than peacock bass. However, if winter temperatures increase, peacock bass could become a threat in South Carolina. Other invasive fish that are common in Florida and, like peacock bass, could become established in South Carolina, include various cichlids, pleco (*Hypostomus plecostomus*), Asian swamp eel (*Monopterus albus)*, walking catfish (*Clarias batrachus*), various piranha and oscar (*Astronotus ocellatus*). All of these fish could, like tilapia, compete with native species for habitat, food and spawning resources.

Despite the increased frequency of occurrence, and in some cases the establishment in South Carolina, of subtropical and tropical flora and fauna, including invertebrate fauna, with historic ranges once restricted to latitudes south of Cape Canaveral, little has been done to determine the impact of these species on the natural ecosystems of our state, or to assess whether or not their arrival and dispersal has been enhanced or accelerated by climate changes. Recently it has been demonstrated that changes in seasonal maxima and minima of water temperature may be more important than changes in means.[142] Examples of marine invertebrates that have extended their ranges northward include two millennia Andrew C. Kemp, Benjamin P. Hortona,,

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[141]Pelicice, F.M. and A.A. Agostinho. 2009. Fish fauna destruction after the introduction of a non-native predator (*Cichla kelberi*) in a neotropical reservoir. Biol Invasions. 10.1007/s10530-008-9358-3.

[142] Stachowicz, J, J Terwin, R Whitlatc, and R. Osman. 2002. Linking climate change and biological invasions: Ocean warming facilitates nonindigenous species invasions. Proc. Natl. Acad. Sci. 99(24):15497-15500.

Jeffrey P. Donnellyc, Michael E. Mannd,species of callinectid crabs similar to native blue crabs (*Callinectes bocourti* and *C. exasperatus*); the spiny hands crab (*Charybdis hellerii*); the blue land crab (*Cardisoma guanhumi*); the green porcelain crab (*Petrolisthes armatus*); two pulmonate snails (*Creedonia succinea* and *Microtralia ovula*); an intertidal littorinid snail (*Echinolittorina placida*); the Asian green mussel and the charrua mussel (*Perna viridis* and *Mytella charruana*); the Asian tiger shrimp (*Penaeus monodon*); two acorn barnacles (*Megabalanus coccopoma* and *M. tintinnabulum*); and a caprellid amphipod (*Caprella scaura*).[143] In addition, lionfish (*Pterois volitans*) have colonized the southeastern United States from Florida to North Carolina over the past decade.[144] These represent some of the most recently discovered arrivals, although others are certain to arrive in the future. Invasive species can be extremely problematic because they may competitively displace existing species or cause radical habitat changes that affect entire populations or ecosystems. For example, beach vitex (*Vitex rotundifolia),* an introduced exotic plant from Hawaii, recently has taken over sand dune areas on some beachfronts in northern Georgetown and Horry counties. Its aggressive growth and impenetrable roots quickly cover dunes, making them unsuitable for loggerhead sea turtle nesting.[145] Species such as *Phragmites australis*, *Hydrilla verticillata* and *Eichhornia crassipes* are aquatic plants with similar impacts to brackish and freshwater areas in the United States where they create monocultures outcompeting native species and drastically altering the ecology of entire ecosystems. Another example is the nematode *Anguillicoloides crassus*, a parasitic worm originally located only in Asian eels (*Anquilla japonica*). The first record of *A. crassus* in wild-caught American eels (*Anguilla rostrata*) was from Winyah Bay in 1996,[146] having been introduced by the transport of live Asian eels. The parasite is much more detrimental to the health of American eels than its natural host, and it may exacerbate problems in this already declining species by interacting with other sources of stress, such as climate change. (Martin Vermeere, and Stefan Rahmstorff www.pnas.org/cgi/doi/10.1073/pnas.1015619108)

The recent range expansions of native North American mammals, specifically coyotes (*Canis latrans*), into South Carolina raise questions about the role climate change has played or may play in this phenomenon. Obviously, ranges have expanded and contracted over time but, more recently, it has become clear that transport and release by humans have placed animals and plants in new areas, and these species have occupied available habitats. In many cases they then compete directly with native species, to their detriment. The principal of natural range expansion is difficult to detect and describe and naturalization is difficult to determine.

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143 South Carolina aquatic invasive species management plan. Prepared in coordination with the South Carolina Aquatic Invasive Species Task Force by the South Carolina Department of Natural Resources. September 2008. 94 pp.

144 Albins, M. and M. Hixon. 2008. Invasive Indo-Pacific lionfish *Pterois volitans* reduce recruitment of Atlantic coral-reef fishes. Mar Ecol. Prog. Ser. 367:233–238.

145 Murphy, S. and D. Griffin. 2005. Loggerhead turtle - *Caretta caretta.* 2006. http://www.dnr.sc.gov/cwcs/pdf/Loggerheadturtle.pdf. Last accessed Dec 2010.

146 Fries, L.T., D.J. Williams and S.K. Johnson. 1996. Occurrence of *Anguillicola crassus*, an exotic parasitic swim bladder nematode of eels, in the SE United States. Trans. Am Fish. Soc. 125:794-797.

Recently, the armadillo (*Dasypus novemcinctus*) expanded its range into South Carolina from points south and west, and the federally endangered wood stork (*Mycteria americana*), that historically nested in Florida, now nests in significant numbers in this state. The available literature does not describe climate change as a factor in this expansion. Habitat loss and alteration for nesting and foraging are most often described as the major factors for range expansion of the wood stork.

Of greater threat are species currently located in Florida and South Georgia that come from more temperate parts of the world but have been historically limited to ranges south of South Carolina by cold winters. Significant climate change could allow northward and eastward range expansion in these species that would be detrimental to native species. Plants, birds, reptiles (especially large constrictors), amphibians and a few mammals are now reproducing in areas south of South Carolina. Inventory and monitoring is essential to determine and describe any changes in range of these exotic species.

3.2.3.2 DNR Response and Recommendations

DNR should continue monitoring wildlife and fish populations and their habitats for evidence of new invasive and non-indigenous species. Through existing programs within DNR, South Carolina needs to consistently fund and expand control activities to eliminate or reduce concentrations of those species where possible. DNR and others should seek to strengthen State laws regulating importation and transportation of non-native species and to implement the action items delineated under the goals and objectives of the South Carolina Aquatic Invasive Species Management Plan.

DNR is a partner in the South Carolina Aquatic Invasive Species Task Force and, through the Aquatic Nuisance Species Program, collaborates with the South Carolina Aquatic Plant Management Council to annually develop a South Carolina Aquatic Plant Management Plan. DNR also is active on regional levels with the Gulf States and South Atlantic Panel and on state levels with the South Carolina Exotic Plant Pest Council. Similar strategies to address nuisance and exotic species, particularly on conservation lands should be expanded within the state. Support is needed to develop and implement a comprehensive, prioritized monitoring strategy for the early detection of non-indigenous species. DNR also should seek to partner and collaborate with others working in this area.

Support of taxonomic expertise is an important component of any successful invasive species monitoring program. The Southeastern Regional Taxonomic Center (SERTC), located in the MRRI, has developed a curated collection of marine and estuarine animals from the SAB and maintains a searchable library of regionally relevant peer-reviewed taxonomic literature. Through collaborations with other labs and museums, SERTC has collected and preserved representative specimens from numerous habitats throughout the southeastern United States, documenting northern range extensions along the Atlantic Coast. Continued funding for this program needs to be secured. The

Center played an important role in developing the management plan for South Carolina aquatic invasive species.[147]

Prevention may be the best adaptive strategy to minimize the impact of invasive species. Enforcement of existing statutes related to intentional importation of non-indigenous species, such as apple snails (family *Ampullariidae*), is essential. Enforcement mechanisms should be strengthened; however, a review of all statutes and regulations regarding importation of non-indigenous organisms is recommended, with the legislative goal of a consolidated, comprehensive state law to minimize intentional and accidental introduction. A rapid response plan to eradicate, contain or control invasive species also is an essential tool to curtail the spread of invasive species.

3.2.4 **Potential for Increased Incidence of Pathogens**

3.2.4.1 Increased Incidence of Pathogens

Climate warming has been linked with a general increase in pathogens, which may have negative effects on host populations.[148]

The oyster disease Dermo (*Perkinsus marinus*) has been determined to be ubiquitous in South Carolina oysters although infection intensities are relatively low.[149] Infection intensities have consistently been relatively low, perhaps because Palmetto State oysters are almost exclusively intertidal and exposed to high summer temperatures that may inhibit the disease.[150] Another oyster disease, MSX (*Haplosporidium nelson*) has been infrequently detected in South Carolina and it is not known how climate change may affect the prevalence of this pathogen.

An apparent outbreak of disease caused by the hemolymph-infecting dinoflagellate *Hematodinium* in the late 1990s in Georgia reportedly led to substantial mortalities in blue crabs and other crustaceans. It is believed that the outbreak was initiated by a prolonged drought that resulted in higher salinities in estuaries, thus favoring the growth of *Hematodinium*.[151] In many South Carolina estuaries, blue crabs can escape to lower salinity refuges, but in the northern part of the state these refuges may not be available. Knowledge of the dynamics of hosts and pathogens in the marine environment is limited, but where disease outbreaks occur, they often are associated with unusual

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[147] South Carolina Department of Natural Resources. 2008. South Carolina aquatic invasive species management plan. http://www.dnr.sc.gov/invasiveweeds/aisfiles/SCAISplan.pdf. Last accessed Dec 2010.

[148] Harvell et al. 2002. Climate warming and disease risks in terrestrial and marine biota. Science 296: 2158-2162. Hereafter Harvell et al. 2002.

[149] Bobo, Y., D. Richardson, L. Coen and V. Burrell. 1997. A report on the protozoan pathogens *Perkinsus marinus* (Dermo) and *Haplosporidium nelson* (MSX) in South Carolina shellfish populations. SC DNR Mar. Res. Div. Tech. Rept. No. 86. 50 pp.

[150] Bushek, D. 1997. Chlorine tolerance of the eastern oyster pathogen, *Perkinsus marinus*: Standards for sterilization and quarantine. Grant # P/M-2A, SC Sea Grant Consortium Final Rept.

[151] *Hematodinium* Continues - No Let-Up in Sight. 2002. The Georgia Blue Crab Journal. http://crd.dnr.state.ga.us/assets/documents/BlueCrabNewsletterapr02.pdf. Last accessed Dec 2010.

climatic events.[152] The potential for outbreaks of new pathogens is high because of the expectation of greater variation in climate over the next few decades and invasion of species carrying non-native pathogens.

Large-scale disease mortality in wild penaeid shrimp has not been observed in South Carolina; however, disease and mortality in nonnative shrimps in aquaculture farms within the state has been documented. Cultured shrimp are vulnerable to a number of viruses with susceptibility varying among species, but thus far, no known mortality has occurred in the wild populations of South Carolina. Because pathogenic viruses are known to exist and shrimp are more vulnerable when exposed to multiple stresses, including high temperature and salinity, additional stresses caused by climate change may have a negative effect on wild populations.[153] [154] A pathogen that is known to affect wild shrimp is the black gill (brown gill) syndrome. This condition is caused by an apostome (protozoan) that attaches to shrimp gills and causes melanization, or a darkening of the chitinized exoskeleton. This disease typically is most common when coastal waters are warmest in August and September.[155] Although no directly related mortality has been documented, it is clear that shrimp stamina, ability to escape predators and probably resistance to disease are compromised by the condition. The lowest incidence of the disease since 1999 occurred in 2001 following a relatively cold winter. These apparent relationships to water temperature may suggest that warmer winters and summers associated with climate change may amplify the disease.

Changes in temperature regimes may result in an increase in wildlife and fish diseases that are adapted to warmer conditions. Warmer temperatures can increase the potential for invasion by new pathogens, or increase risk of more serious invasions by existing pathogens. Not only could such pathogens affect wildlife and fish, effects to native vegetation could alter habitats and make them unsuitable for native species. Sudden oak death and the hemlock wooly adelgid infestations are already changing the landscape of some of South Carolina forests, making them potentially more vulnerable to invasion.

3.2.4.2 DNR Response and Recommendations

A proactive program monitoring the health of aquatic animals is not feasible. The potential pathogen pool is large and resources and tools are limited. The most adaptive approach is vigilance for potential pathogens and collaboration with the Clemson Veterinary Diagnostic Center. Advances in molecular technologies have developed a broad range of diagnostic tools that allow scientists to assess thousands of known pathogens in a single assay. It is not known if similar tools for other species are available. Efforts to monitor interstate movement of potentially infected animals should

[152] Harvell et al. 2002.
[153] Zein-Eldin, Z. and M. Renaud. 1986. Inshore environmental effects on brown shrimp, *Penaeus aztecus,* and white Shrimp, *P. setiferus,* populations in Coastal waters, particularly of Texas. Mar. Fish. Rev. 48(3):9-19.
[154] Zhan, W., Y. Wang, J. Fryer, K. Yu, H. Fukuda and Q. Meng. 1998. White spot syndrome virus infection of cultured shrimp in China, J. of Aquatic Animal Health 10:405-410.
[155] Whitaker, D., J. Powers, B. Gooch, N. West and A. Von Harten. 2009. Cooperative research in South Carolina – SC DNR Final Report to National Marine Fisheries Service NOAA, Grant Number NA04NMF4720306. p 45-49.

be continued and enhanced. Research should continue for the development of diagnostics, particularly field tests that can be used to identify pathogens.

Continued support is needed to monitor wildlife and fish populations and their habitats for evidence of new disease and parasite infestations. DNR should maintain and strengthen regional and national contacts and interactions related to disease and parasite challenges, including participation in the Southeastern Cooperative Wildlife Disease Study.

3.3 Impacts to Commercial and Recreational Fishing and Hunting and Other Public Uses of Natural Resources Resulting from a Changing Climate

3.3.1 Potential for Changes in Recreational and Commercial Opportunity

Wildlife and fish populations likely are to be altered as climate change occurs. Such changes may result in reduced commercial and recreational hunting and fishing opportunities of some species, although opportunities may increase with others. As populations are monitored, it may become necessary to alter seasons or bag limits on some species. It will be important to keep the public notified of changes as they occur in order to reduce the potential for conflict between human and natural resource needs and values.

3.3.2 DNR Response and Recommendations

Long-term monitoring of harvested species should be conducted in order to detect temporal and spatial changes in numbers and prevent unsustainable population declines. Research is needed to model and understand the relationship between climate change and population dynamics of important species. Outreach and education are required so that South Carolina residents, city and county officials and legislators understand changes in natural resources resulting from climate change. Strategies and policies are needed to establish compromises that balance needs of the resource with human needs and uses.

3.4 Natural Resources Education and Outreach Needed as a Result of a Changing Climate

3.4.1 Needs for Climate Change Impacts Education and Outreach

Climate change potentially will cause significant alterations to the nature and structure of habitats and species distributions in the southeastern United States including South Carolina. Coastal communities, in particular, will become increasingly vulnerable to a wide range of hazards including hurricanes, shoreline erosion, flooding and storm surge. The impact of these hazards is compounded by coastal development as coastal population increases and coastal ecosystems are degraded. A resilient community understands the potential impacts of these hazards and prepares itself to respond with timely and holistic management strategies. This gives communities the ability to recover after hazard events and adapt to future conditions.

3.4.2 DNR Response and Recommendations

A critical element of the DNR response to climate change is to increase public awareness of the potential adverse, and positive, effects resulting from these changes. Agency efforts at outreach and education are threefold:

1. DNR should strengthen and increase partnerships with other agencies and organizations involved in climate change research and policy and planning. For example, the Southeast Natural Resource Leadership Group (SENRL), an interagency collaboration established to improve communication on natural resource issues, has recognized the need for natural resource agencies to proactively guide policy, management and socioeconomic decision making regarding climate change.[156] The DNR should seek opportunities to participate in national and local networks such as the SENRL and the recently established Southeastern Climate Science Center. National and local networks are a rich source of information, ideas, research and funding opportunities. Participation in such efforts can greatly increase the efficiency and effectiveness of a state climate change response plan.
2. DNR must assist local communities in planning for change and providing coastal resiliency to reduce overall vulnerability of economic and ecological systems to climate variations. The agency's education programs can help inform decision making in the state regarding climate change by strengthening regional and local partnerships for improved community response. Communities will need assistance planning for their response to potential hazards by considering institutional capacity, land development patterns and natural resource conservation. DNR alone cannot respond to the needs of these communities; however, DNR regularly works with partners that can provide access to information and tools designed to help communities identify critical linkages and understand how decisions impact their community and the environment. By strengthening regional and local partnerships, DNR can help respond to the needs of communities by linking them with the information they require.
3. DNR will play an important role in communicating information on climate change to citizens of South Carolina. Through partnerships with educators and policy makers, DNR research and management staff can work with these groups to translate scientific information into action. The agency will use the World Wide Web to publish reports, news articles and other information involving climate change as well as to provide a mechanism for public comment and input into the process. By involving the public in the research process, DNR will build buy-in from the community and capacity at the local level to respond adaptively to future conditions. The importance of resilient communities will increase as the impacts of climate change are felt. In addition, substantial

[156] Southeast Natural Resource Leadership Group. 2008. Meeting notes. 14 pp.

efforts should be made by agency staff to publish their research data and analysis in peer-reviewed scientific journals.

Climate change is a global concern with potentially significant impacts to South Carolina. To understand and assess the impacts to the human and natural resource populations of this state will involve the cooperative efforts of many agencies, scientists and planners as well as the local community. Education of the state's citizens on the negative and positive impacts of climate change is an essential component of this process. Each of these outreach initiatives is critical to improving the state's capabilities to respond and adapt to climate change. Through regional, state and national partnerships, DNR can help communities protect themselves and the important natural resources surrounding them.

3.5 Technologies Needed to Mitigate and Protect Natural Resources as a Result of a Changing Climate

3.5.1 Technologies Needed to Monitor Physical and Biological Change

Understanding and monitoring climate change impacts on the state's natural resources will require the enhancement of the agency's technology infrastructure, database and analysis and modeling capabilities. Various DNR programs have collected natural resource data for the state, and these historic and recent data are maintained in disparate database systems. For example, the South Carolina Climate Office records hourly and daily temperature, precipitation, storm event and other meteorological data from numerous weather stations throughout the state. These data are stored in Oracle and are used by staff in regional drought analysis and monitoring studies. Similarly, the South Carolina Geological Survey and the USGS established cooperative programs to record surface and ground water and lithologic data from various river/stream gauges and well monitoring stations. These data primarily are maintained in Oracle with some tables residing in Microsoft Access. WFFD maintains numerous fisheries, wildlife, botanical and other habitat-related databases in a variety of mainframe, server and PC-based database management systems.

MRD has a variety of long-term data sets containing both physical and biological data. For example, MRRI maintains several long-term fishery and water-quality databases that are relevant to evaluating the effects of climate change on those resources. These include: the MARMAP fishery independent monitoring program of offshore (deepwater) reef fish that extends back 20+ years and the SEAMAP fishery independent monitoring program of nearshore non-reef finfish and crustacean species that also extends back 20+ years. Both of these programs collect data from Cape Hatteras to Cape Canaveral that includes basic water quality measures and both use standardized sampling programs that facilitate long-term trends analysis. MRRI also maintains a 10-year database of juvenile loggerhead sea turtle distribution and density that extends from about Winyah Bay south to and including the northern portion of Florida.

To facilitate inshore monitoring, the MRRI conducted a standardized trammel netting program to assess the composition and abundance of the state's recreational finfish species for 20+ years, and another standardized sampling program to assess the relative abundance and distribution of shrimp and blue crabs that is also 20+ years in duration. The MRRI also participates in several programs to determine and assess environmental measures affecting coastal resources. In cooperation with DHEC, the MRRI has conducted an annual statewide assessment of water quality, sediment quality and biological resources for bottom invertebrate fauna, fish and crustaceans since 1999. The ACE Basin NERR program also has nearly continuous water quality and weather data extending back to 1995 and this program is expected to continue to be maintained in the future.

Mining these various data sets for long-term trends is a critical need, but the data are stored in a variety of formats and in many cases are not in advanced information management systems. Therefore, it is strategically important to develop a comprehensive spatial and tabular database of existing natural resources data and integrate various analytical, statistical and modeling tools to forecast trends and project changes in the distribution of these resources in response to climate change.

DNR also has extensive natural resources spatial data in the agency's geographic information system. These data include statewide soils, wetlands and land use, hydrography, known threatened and endangered species locations, road centerlines, administrative boundaries, contours, digital elevation models, agency owned and/or managed lands and boat ramps, surface and subsurface geology, multi-temporal digital orthophoto quarter quadrangles and Landsat Thematic Mapper satellite imagery. Statewide land cover data was classified from Landsat TM data for the 1985/86, 1992/93, 1997/98, 2002/03 and 2008/09 time periods. These data can be used to provide baseline trends in habitat change and to project potential future impacts from climate change and sea-level rise. Similarly, MRD has developed new oyster maps that provide detailed base imagery and shape files of intertidal shellfish resources. These imagery products also could be used to evaluate changes in wetland vegetation extent and distribution over time which has tremendous potential value in evaluating loss of wetlands and shellfish due to sea-level rise. More recently, the agency initiated a statewide program to develop high resolution elevation data using Light Detection and Ranging (LiDAR) technologies. These data provide digital elevation models with a vertical accuracy of 15.0 to 18.5 cm in open terrain which is essential for sea-level rise and wetland change modeling.

3.5.2.1 DNR Response and Recommendations

In order to meet the agency's long-term needs for responding to climate change impacts in South Carolina, numerous additional strategies and technologies will be required to include:

1. DNR needs to implement a resource inventory and monitoring program to track trends in resource abundance and distributions at the species and landscape

levels as determined to be viable and appropriate to the agency mission. This inventory will require input from all sections and groups, and should expand upon existing data collection and monitoring programs as discussed in Section 3.5.1. Further, it should include the use of various satellite image processing data and tools to systematically assess changes to the vegetative structure and man-made landscape features of the state. Access to accurate, long-term monitoring databases is critical for developing strategies to respond to climate change impacts; therefore, implementation of these comprehensive monitoring programs should be considered a priority.

2. The agency must expand its existing technology infrastructure to support the climate change studies. This includes the implementation of various direct and remotely-sensed measurement platforms to provide *in situ* documentation of sea-level rise, temperature and precipitation, stream flow and other critical data and the integration of all data collected through agency resource inventories in a comprehensive Oracle database. Coupled with various data mining and warehousing technologies, this would enable examination of data for trends and patterns useful for understanding climate change impacts. Further, as these long-term data and information are recorded and analyzed, additional network bandwidth, data storage and computational processing capabilities will be required to support the volume and complexity of scientific, graphic, GIS, imagery and video applications. Additionally, partnerships should be established with other southeastern states and academic institutions to develop a standardized data schema and information delivery platform that will facilitate sharing/exchange of regional data, analysis results and reports.
3. DNR also must develop appropriate data access, scientific analysis (statistical, biometric, image processing, spatial modeling and forecasting, etc.) and resource management decision-support tools to assess the impacts of climate change and develop appropriate management strategies. These tools must include business intelligence and data mining technologies to discover patterns inherent in the data and extensive use of the World Wide Web to disseminate relevant information to the public regarding climate change and its impacts to the state's natural resources. Where available, the agency should implement commercial-off-the-shelf (COTS) solutions that can be augmented with software and applications developed by agency programming staff that address issues specific to natural resources management in South Carolina. For example, the Sea Level Affecting Marshes Model (SLAMM) developed by the United States Fish and Wildlife Service can be adapted from its general visualization modeling application to incorporate high resolution LiDAR elevation and soils data to model potential impacts of sea-level rise on salt and brackish marshes along the coast. Other software tools appropriate to the needs of the DNR are available from various federal and state governments including numerous sea-level rise and biodiversity impact assessment technologies developed by the NOAA Coastal Services Center. These assessment tools should be evaluated for application to the needs of the DNR for determining climate change impacts in the state.

4. Finally, DNR must develop the expertise required to meet the challenges of understanding and addressing the vast array of environmental impacts and natural resource management issues associated with climate change. Staff training in various analytical, modeling and geographic information systems software and associated technologies is essential. Similarly, sponsorship and participation in various regional programmatic workshops and technical committees are critical for developing and maintaining strategic climate change response initiatives.

The creation of long-term monitoring programs, implementation of new technologies and establishment of regional partnerships are essential components of the DNR's response to climate change in South Carolina. The efforts required to accomplish these key objectives may be facilitated by outside funding sources, as many grant opportunities now support or require the development of digital data and implementation of innovative technologies. Additionally, cooperative partnerships facilitate information sharing, which increases the efficiency and effectiveness of programs and opens opportunities for additional funding sources.

4.0 NATURAL RESOURCES LAW ENFORCEMENT DURING AN ERA OF CLIMATE CHANGE

The Law Enforcement Division (LED) is responsible for enforcement of state and federal laws governing hunting, recreational and commercial fishing, recreational boating and other natural resources conservation concerns; promoting safety and developing public support through education and outreach. Additionally, the LED is tasked with assisting other state and federal agencies with varying security missions dealing with non-natural resource issues and events.

Climate change can no longer be considered solely an environmental issue. The physical effects of climate change will have both natural resources impacts as well as socio-economic impacts including the loss of infrastructure, resource scarcity and displacement of life and property. In turn, these impacts could produce security consequences to include civil unrest and instability, presenting new challenges to law enforcement agencies and governments attempting to maintain order and rule of law.[157]

[157] Abbot, C. 2008. An uncertain future: Law enforcement, national security and climate change. Oxford Research Group. http://www.bvsde.paho.org/bvsacd/cd68/uncertain.pdf. Last accessed May 2010.

Table 4.1 Anticipated public safety effects related to climate change in South Carolina.[158]

Weather Event	Public Safety Issue	Population Affected	Public Safety Burden
Heat waves	Heat stress	Elderly, socially isolated, poor, those already health impacted	Low to moderate
Increase in mean temperature	Heat stress, increased disease	Outdoor workers, elderly, poor, outdoor recreationalists	Low to moderate
Extreme weather events	Injuries, drowning	Coastal and Lowcountry dwellers, the poor, outdoor recreationalists	Moderate
Severe winter weather	Injuries, hypothermia, drowning,	Elderly, poor, outdoor recreationalists	Moderate
Sea-level rise	Injuries, drowning, water and soil salinization, ecosystem and economic disruption	Coastal and Lowcountry dwellers, outdoor recreationalists	Moderate
Drought, ecosystem migration	Water shortage, low rivers and lakes, boating accidents, food shortage	Elderly, children, poor, outdoor recreationalists, multiple populations	Moderate to high
Floods	Excess water, dam failures, crop losses, livestock loses, loss of pollution containment, loss of human life	Multiple populations	Moderate to high
Severe climate change	Heat stress, drowning, water shortage, limited food availability, human conflict	Multiple populations	High

4.1 Marine Law Enforcement

4.1.1 Marine Law Enforcement Issues

Marine law enforcement primarily is responsible for enforcing recreational and commercial fishing laws, promoting boating safety and investigating boating incidents in the marine environment. DNR officers regularly conduct search and rescue missions in outlying areas and assist other law enforcement agencies in investigations. The LED has officers trained in underwater diving to assist in law enforcement, search and rescue and evidence recovery missions. The Division also utilizes aircraft for law enforcement patrol, search and rescue and other department missions. The LED is called upon to provide homeland security missions related to waterborne activities including, but not limited to, commercial ship escorts and port security.

[158] Balbus, J.M. and M. L. Wilson. 2000. Human health and global climate change: A review of potential impacts in the United States. Washington, DC: Pew Center on Global Climate Change. http://www.pewclimate.org/docUploads/human_health.pdforg/global-warming-in-depth/all_reports/human_health. Last accessed Oct 2010.

As certain species adapt to climate change some will shift ranges creating additional opportunity for commercial and recreational fishing in the marine environment. These shifts in range and availability will be magnified by human population growth and additional resource pressure. Sensitive habitats may be threatened, requiring additional monitoring and patrols to stem illegal activities and overharvests. The need for conservation enforcement will become apparent as this process unfolds. In view of the possible decline of food resources there will be ever increasing pressure to push the boundaries of conservation to meet economic and food supply needs. In the case of a catastrophic event these issues will manifest themselves at the most basic level, where everyday citizens stressed by poor economic and environmental conditions will begin subsistence fishing by harvesting whatever is available to meet daily needs. Law enforcement will be the only line of defense between these individuals and overharvesting of species. Additionally, alternative energy development will usher in a new set of law enforcement issues in order to monitor and protect marine energy development infrastructure.

In addition to resource protection, the LED may be faced with an increasing recreational boating population along our coastline as a result of higher temperatures and possible longer boating seasons. As a result, enforcement of recreational boating may not be readily available if the current trend of reducing officer positions continues.

4.1.2 DNR Response and Recommendations

Funding for an adequate, if not expanding, natural resource law enforcement presence in the marine environment will be necessary. Partnerships with federal and other state and local law enforcement agencies will be required.

4.2 Inland Law Enforcement

4.2.1 Inland Law Enforcement Issues

As in the marine environment, the LED is responsible for enforcing recreational and commercial fishing laws, promoting boating safety and conducting boating incident investigations on inland surface water bodies. DNR officers regularly conduct search and rescue missions in the air and on or under the surface of rivers, lakes and ponds assisting other law enforcement agencies in investigations. The LED performs homeland security missions related to waterborne activities near hydroelectric dams, nuclear facilities and other energy production facilities. Additionally, the LED is tasked with protecting land-based game and non-game species as well as investigation of hunting related incidents.

Climate change may shift ranges of popular species pursued through recreational hunting and fishing, bringing pressures on sensitive species and habitats; such as the threat that warming and drought imposes on aquatic species, for example, trout and anadromous fish. These threats will be magnified by human population growth and additional resource pressures. Sensitive habitats may be threatened, requiring additional monitoring and patrols to stem illegal activities and over harvests.

As within the marine environment, the need for conservation enforcement will be apparent as this process unfolds. With ever increasing pressure to push the boundaries of conservation to meet economic and food supply needs, every day citizens stressed by poor economic and environmental conditions will begin subsistence fishing and hunting by harvesting whatever is available to meet daily needs. Law enforcement will be the only line of defense between these individuals and the overharvesting of species.

Additionally, as higher temperatures and longer seasons become stabilized, the LED will be faced with an ever increasing recreational boating population. As a result, enforcement of recreational boating activity may not be readily available if the current trend of reducing officer positions continues.

4.2.2 DNR Response and Recommendations

Funding for an adequate, if not expanding, natural resource law enforcement presence in inland areas will be necessary. Partnerships with federal and other state and local law enforcement agencies will be required.

4.3 Public Safety

4.3.1 Public Safety Issues

The potential public safety effects of climate change have been extensively reviewed.[159] Many are health and safety related. Principal public safety concerns include those related to severe weather events and heat waves. Indirect concerns, for which data to support projections are less available and uncertainties are greater, include human competition for available resources, population dislocation and civil conflict/unrest. In addition, changes in the patterns of pests, parasites, and pathogens may affect wildlife, agriculture, forests and coastal habitats and can alter ecosystem composition and functions. Climate change may disrupt these life-support systems and carry implications for public safety.

Very few public safety laws and regulations currently have a direct bearing on climate change. However, public safety officials can provide science-based input regarding laws and regulations affecting the environment, natural resources and alternative energy arenas. As policies are codified, there may be roles for state and local public health agencies in enforcing such policies including water quantity and quality regulations as an example.

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[159] Frumkin, H., J. Hess, G. Luber, J.Malilay and M. McGeehin. 2008. Climate Change: The Public Health Response. Am. J. Public Health. 98:435-445. http://www.bvsde.paho.org/bvsacd/cd68/HFrumkin2.pdf. Last accessed Sept 2010.

4.3.2 DNR Response and Recommendations

There is widespread scientific consensus that climate is changing and it also is being reported in the public safety arena.[160] Mounting evidence suggests there will be future impacts on public safety, including illnesses and injuries associated with heat stress and exposure. Other future impacts will include incidents related to drought caused by shallow surface waters, severe weather events and floods. Finally there are likely to be public safety impacts to surface- and ground-water supplies. Indirect effects may include the consequences of mass migration and human conflicts over available resources. Addressing these occurrences to public safety will be a pressing challenge for natural resource and other law enforcement agencies. Although the scope and complexity of the challenges may be unprecedented, the conceptual framework for responding will draw on long-standing public safety policy. An effective public safety response to climate change is essential to preventing injuries and illnesses, enhancing preparedness, and reducing risk. Science-based decision-making will help manage uncertainty and optimize environmental outcomes.[161]

As climate change evolves, the role of natural resources law enforcement will be required to adapt. There will be a need for additional emphasis on protecting dwindling resources requiring the need for enhanced conservation enforcement. Also, public ambivalence to natural resources will become apparent as the need for gathering food becomes a priority at an unknown cost to all fish and wildlife resources. In either case, the role of the LED will evolve with a greater focus on resource enforcement or a greater focus on more traditional roles of law enforcement where public safety is the priority. In either instance, the LED, in the face of an ever-changing world, will continue to play an increasing role in traditional public safety.

[160] IPCC. 2007.
[161] IPCC. 2007.

5.0 SUMMARY AND PRIORITY LIST OF CLIMATE CHANGE ISSUES

5.1 Overarching Issues and DNR Recommendations

This first report from DNR sets the foundation for actions needed to address climate change impacts to natural resources in South Carolina. The report identifies the overriding natural resource issues and provides recommended actions to keep South Carolina at the forefront of conserving natural resources during an era of changing climate. These overarching issues include the potential for:

1. Detrimental change in habitat,
2. Detrimental change in abundance and distribution of species,
3. Detrimental change to biodiversity and ecosystem services,
4. Detrimental change on the traditional uses of natural resources including hunting, fishing, other compatible public uses, forestry and agriculture,
5. Detrimental change in the abundance and quality of water, and
6. Detrimental change in sea level.

Specific tasks identified by DNR in order to move forward in an era of climate change while protecting natural resources include:

1. Spatial mapping,
2. Monitoring and establishing baselines on
    a. Living resources,
    b. Non-living resources, and
    c. Climate trends.
3. Habitat acquisition,
4. Adaptation strategies on DNR-titled properties,
5. Integration and analysis of data,
6. Outreach and education,
7. Developing additional partnerships and collaborating with others, and
8. DNR leading by example.

5.2 DNR Leading by Example

DNR is making climate change an integral part of the agency's ongoing mission. A Climate Change Impacts Technical Working Group (CCI-TWG) was formed with representatives from each division. The CCI-TWG reports directly to the Executive Office and was charged with the completion of this comprehensive report addressing the potential impacts of a changing climate to natural resources in South Carolina. The CCI-TWG developed recommendations that will lead to integrating climate change into the DNR organizational culture, its structure and all aspects of its work. These key steps include:

1. Develop an approach that will incorporate climate change into DNR strategic and operational plans and existing structure that can be used as a vehicle for internal and external communication,
2. Ensure that all levels of agency staff are aware of, and appropriate staff engaged in, climate-change initiatives,
3. Update and align DNR actions with regional and national climate-change initiatives as appropriate,
4. Work with stakeholders and partners on fish and wildlife adaptation and mitigation,
5. Prepare an internal and external outreach strategy to communicate climate change issues, and
6. Develop clear and measurable indicators to track the results of DNR climate change efforts.

To accomplish its mission, DNR recommends the following core climate change foci of effort:

1. Policies and Opportunities – focus on grants, legislation, partnerships and strategic planning,
2. Research and Monitoring – focus on standardized monitoring protocols and state-specific data (including gaps) and predictive modeling,
3. Communication and Outreach – focus on the DNR messages and a climate change communication plan,
4. Adaptation – focus on the activities related to unavoidable climate-change impacts on fish and wildlife, and
5. Operations – focus on positioning DNR as a leader by reducing the agency's carbon footprint, improving its energy efficiency and decreasing operational costs by accomplishing the following:
    a. Achieve increased fuel economy through fleet reduction, use of more efficient vehicles as well as implementing efficient wildlife and fisheries management and law enforcement where combustion engines are required,
    b. Achieve increased energy efficiency through obtaining energy audits for agency buildings and adoption of practicable energy audit recommendations,
    c. Implement practicable water efficiency measures for agency buildings, and
    d. Implement paperless internal communications and document management.

DNR is taking a lead role among South Carolina state agencies to advance the scientific understanding of the vulnerability of South Carolina's vital natural resources during an era of changing climate. These actions and advocacy for sound planning should enable the agency, its partners, constituents and all Palmetto State citizens to avoid or minimize the anticipated impacts. The agency will strive to lead by example, work to create ecosystem resiliency and partner with others to preserve and protect South Carolina’s natural resources.

American Shad Habitat Plan Update

State of Florida

Florida Fish and Wildlife Conservation Commission
Fish and Wildlife Research Institute
Division of Marine Fisheries Management

Reid Hyle
reid.hyle@myfwc.com

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Introduction

Amendment 3 to the Interstate Management Plan for Shad and River Herring cites habitat loss and degradation as major factors in the decline of and continued depression of populations of American Shad along the Atlantic coast and requires member states to develop habitat plans for American Shad in their jurisdiction. This plan is submitted to serve as the required habitat plan for the State of Florida. It outlines historic and current habitats available to American Shad in Florida and identifies known threats to those habitats as well as efforts to mitigate those threats.

The primary spawning run of American shad in Florida historically was and currently is in the St. Johns River. The only other river lying within Florida in which spawning has been documented historically (Williams and Bruger 1972) and recently (Holder et al. 2011, Dutterer et al. 2011) is the Econlockhatchee River which is a tributary to the St. Johns River. The St. Marys River is along the eastern border between Georgia and Florida historically supported a population of American Shad. This plan includes these three systems.

The Ocklawaha River is the largest tributary of the St. Johns River and is the largest Atlantic drainage river in Florida obstructed by a dam in its lower reaches. There is no record of a spawning run of American Shad in the Ocklawaha River pre-dating construction of the dam in 1968. However, the Ocklawaha River is discussed briefly at the end of this plan because advocates for removal of the dam often cite American Shad as among migratory species that would benefit from dam removal.

St. Johns River

1) Habitat Assessment

   General: The St. Johns River emerges from the headwater marsh in Indian River and Brevard Counties and flows approximately 450 km north to the mouth in Jacksonville. Several broad shallow lakes lie within the run of the river. Stream gradient is small with the river bottom dropping 4 m between rkm 450 and rkm 314. The river bottom is at or below mean sea level downstream of rkm 314. American Shad spawn in the St. Johns River from January through April which corresponds to the declining flows of Florida’s dry season (Kelly and Gore 2008).

   a. Spawning Habitat

      i. Historic spawning grounds were documented from rkm 230 to rkm 433 near the headwaters (Williams and Bruger 1972). Of that distance 160 km can be classified as river and 43 km as lake. Primary spawning grounds were in river habitats between rkm 275 and rkm 360 (Williams and Bruger 1972).

ii. A weir built at the outlet of Lake Washington (rkm 415) in 1976 blocks access to approximately 14 km of potential spawning habitat in the uppermost river. Current spawning habitat identified by egg collection (Miller et al. 2012b) and telemetry (Dutterer et al. 2011) is between rkm 230 and the weir at rkm 415. Primary spawning areas are still between rkm 275 and 360. Approximately 146 kilometers of potential habitat remains available for spawning depending on water level.

b. Rearing Habitat

i. Historical in-river and estuarine rearing habitat included 95 km of river between Lake George and Lake Harney, 260 km^2 of lakes within the run of the river, and 105 km of tidal freshwater estuary between Black Creek and Lake George.

ii. All historical rearing habitats are still available.

2) Threats

a. Barriers

i. Low head dam at rkm 415. Crest height of 3.8m NAVD 1988 is 1 m above the river surface at low stage.

1. Action: None. Dam obstructs access to less than 10% of historical spawning habitat. Preferred habitat is between rkm 275 and rkm 360.
2. Regulatory Contact: St. Johns River Water Management Disctrict (SJRWMD).

b. Water Withdrawals Inventory and Assessment

i. Consumptive use permits are coordinated through the SJRWMD. There is a proposal to allow withdrawal of up to a total of 262 million gallons per day (mgd) of surface water from the basin with a total of 155 mdg from several sites along the middle and upper St. Johns River. The District completed the St. Johns River Water Supply Impact Study (WSIS) in 2012 (Lowe et al. 2012). The intent of the WSIS “was to provide a comprehensive and scientifically rigorous analysis of the potential environmental effects to the St. Johns River associated with annual average surface water withdrawals as high as 262 mgd” (155 mgd from the St. Johns River and 107mgd from a tributary). Chapter 12 focused on fishery impacts of the proposed withdrawals with special consideration given to anadromous herrings in appendix 12-C (Miller et al. 2012a and 2012b). Key findings are as follows.

1. WSIS found that impingement/entrainment of anadromous herring eggs and larvae could occur at all proposed intake sites and could be potentially significant at two locations under consideration. The WSIS recommended reducing the impingement/entrainment risk to alosines by considering: intake designs that are safer for ichthyoplankton, alternative intake locations to avoid core spawning locations of American Shad, and curtailing withdrawals on the spawning grounds during the spawning season at sites with high egg/larval abundance.
2. WSIS found that optimal spawning habitat for American Shad as delineated by depth and velocity shrinks under low flow conditions. WSIS finds that access to spawning grounds and acreage of spawning grounds will not be adversely affected by withdrawals due to offsetting effects of base flow augmentation by the Upper Basin Restoration Project. The frequency and duration of low flow events are expected to decline only slightly under modeled expected scenarios.

FWC should coordinate closely with SJRWMD after consumptive use requests for surface water withdrawals have been submitted by an applicant, to ensure the requested withdrawals will not negatively impact American Shad. In particular, withdrawals should not interfere with the ability of American Shad to reach their spawning grounds, nor should potential egg/larval entrainment be excessive. Coordination should include review of potential hydrologic impacts of the proposed withdrawals, assistance with selection of preferred withdrawal sites and assistance with intake design.

The City of Deltona secured a permit from the US Army Corp of Engineers in 2020 to construct a raw water intake on the north shore of Lake Monroe. The project consists of a 0.92 acre intake basin in the littoral zone adjected to the Enterprise Boat Ramp (Latitude 28.862681° Longitude -81.252439°). The basin will feed a 30-inch raw-water main that will deliver water to the Alexander Avenue Water Resources Facility and Rapid Infiltration Basin. The intake is far from the run of the river and not expected to pose a risk to egg, larval, or juvenile shads. The ACOE finding was of no substantial adverse impact to EFH or federally managed fisheries. The project is intended to offset over-pumping of ground water that adversely affects base flow from Blue Spring which discharges to the St. Johns River at river kilometer 248.

c. Water Quality
   i. Nutrient loads are high in the St. Johns River Basin which results in cyanobacteria dominated algae blooms and occasional hypoxia both in freshwater reaches and in the brackish estuary near the river mouth (Hendrickson et al. 2003). Algae blooms may occur in the lower river from summer through early fall which can negatively alter zooplankton communities (Paerl et al. 2002). Reduction in DO may impact larval and juvenile American Shad nursery habitat and/or juvenile emigration corridors. Florida Department of Environmental Protection (FDEP) has established Total Maximum Daily Loads (TMDL) for nitrogen, phosphorus, and/or DO in the upper, middle, and lower St. Johns River (Gao 2006, 2009, Magley and Joyner 2008). TMDLs for nutrients and DO were created for Crescent Lake and Haw Creek (FDEP 2017 and Rhew 2020). TMDL implementation is carried out through two primary routes.
      1. Nutrient reductions are being carried out following guidelines outlined in Basin Management Action Plans (BMAPs) for the lower and middle SJR as well as Lake Jesup (FDEP 2008, 2012, 2010, 2019). BMAPs were developed by committees representing state agencies as well as public and private entities. BMAPs address both point and non-point sources of nutrient loads to the St. Johns River Basin. Subsequent BMAPs have been established for three first magnitude springs in the middle SJR basin: Volusia Blue Spring, Deleon Springs, and Gemini Springs (FDEP 2018). Specific BMAP action items include tasks such as upgrades to wastewater treatment plants, wastewater reclamation, stormwater retrofits, urban structural BMPs, urban nonstructural BMPs, agricultural BMPs, environmental education, and water quality credit trading. Watershed response to BMAPs is tracked through water quality monitoring carried out by FDEP and SJRWMD. BMAP progress is subject to annual review by the TMDL Executive Committee or Basin Working Group overseeing the water body/basin of concern.
      2. Florida Water Management Districts are instructed by the Surface Water Improvement and Management (SWIM) Act

to develop plans to improve the quality and management of surface water. Plans are cooperative with relevant state agencies and affected local governments participating in plan development. Plans have been developed for the upper, middle, and lower St. Johns River (SJRWMD 2002, 2007, 2008).

FWC should monitor the progress of implementation plans to ensure that water quality goals protect American Shad and communicate additional research findings as needed. Nutrient, chlorophyll, and dissolved oxygen trends have been stable to slightly improving in the main stem of the river although cyanobacteria blooms are still common in the Lower St. Johns River. (Pinto et al. 2020)

d. Channelization and Dredging
   i. Historic alterations in the non-tidal river: Navigational improvements occurred in the non-tidal portion of the river between 1884 and 1945.To enhance navigation numerous bends were cut off by excavating new channels in the river between Lake George's southern inlet (rkm 199) and Lake Monroe's outlet (rkm 265).This excavation straightened the main river channel and created numerous new oxbows. Sandbars were removed to establish a minimum depth of four meters between Palatka and Sanford. Further alteration of the non-tidal portion of the river is not planned.
   ii. Jacksonville is an active harbor for cargo. Deepening of the lower 32 km of the river from the mouth to Jacksonville Harbor is likely. US Army Corps of Engineers has prepared a project assessment including environmental impact assessment (USACE 2014). No immediate threat to shad migration or rearing is apparent from this project. Some loss of lower nursery zone could occur due to salt water intrusion. FWC Fish and Wildlife Research Institute (FWRI) Freshwater Fisheries Research section has added parts of the lower St. Johns River estuary to its list of water bodies for long term fishery montoring. FWRI Fishery Independent Monitoring conducts monthly sampling in the lower St. Johns River from the river mouth to rkm 134.

e. Land Use
   i. The marshes of the upper basin were drained for agriculture and livestock grazing from 1900 through 1970. As much as 62 percent of the floodplain upstream of Lake Harney was drained and much water was diverted out of the basin. Following passage of the National

Environmental Policy Act focus of management of the upper basin turned towards flood control, marsh restoration and enhancement, and improved water quality. The 166,500 acre Upper St. Johns River Basin Flood Control Project consists of four water management areas, four marsh conservation areas and two marsh restoration areas managed by the St. Johns River Water Management District and the USACE (SJRWMD 2007).

ii. Other land use impacts result primarily from urbanization and associated stormwater management challenges. These impacts and their mitigation are quantified in previously mentioned SWIM and BMAP plans as well as in flow modeling in the WSIS.

f. Climate Change

i. The St. Johns River, Florida hosts the southernmost spawning run of American Shad on the U.S. Atlantic Coast. Predicted global warming could shorten the spawning season by advancing the date at which temperature exceeds that suitable for spawning. The river bottom of spawning grounds between rkm 230 and 314 is below sea level. Current mean water surface height of the St. Johns River is above sea level down to rkm 230. Predicted sea level rise could impact these lower spawning reaches. Altered dry season rainfall patterns could change the quantity and quality of water available for spawning and rearing.

ii. Florida FWC has formed a Climate Change Team that includes a Steering Committee and four employee workgroups on adaptation, research and monitoring, communication and outreach, policy and opportunity.

Econlockhatchee River

1) Habitat Assessment

General: The Econlockhatchee River is the second largest tributary to the St. Johns River encompassing a watershed area of 700 km^2 with a stream length of 57 km. It discharges into the St. Johns River at rkm 317. American Shad spawning has been documented in the lower Econlockhatchee River (Williams and Bruger 1972, USACE 1973). It is not known if the Econlockhatchee River supports its own run of American Shad or if it attracts strays from the adjacent St. Johns River spawning grounds. Monitoring by FWC has found that the relative abundance of spawning American Shad can be high in the Econlockhatchee River compared to the adjacent St. Johns when flows are high in the Econ compared to the St. Johns (Hyle et al., 2019)

a. Spawning Habitat: There are no barriers. Historical extent of spawning in the Econlockhatchee River is not confirmed but surveys in March 1969 found adult American Shad as far upstream as the confluence with the Little Econlockhatchee River. Recent electrofishing and telemetry surveys have located adult shad from rkm 4 to rkm 14 during the spawning season (Holder et al. 2012, SJRWMD 2011).
b. Rearing Habitat: Econlockhatchee River shares rearing habitat with the St. Johns River.

2) Threats
   a. Water Quality: Stormwater Management. Portions of the Econlockhatchee River watershed are densely developed which affects stormwater flow patterns and pollution. Management of associated run off is covered by the Middle St. Johns River Basin SWIM plan (SJRWMD 2002). Land use changes and flow augmentation by treated wastewater enhanced Econlockhatchee River base flows starting in the mid-1980s (German and Adamski 2013). Stormwater diversion and reclamation could reduce pollutant loads to the Econlockhatchee River but could also reduce base flow during the winter dry season in which American Shad spawn.

St. Marys River

The St. Marys River originates in the Okeefenokee swamp and flows 203 km to the Atlantic Ocean along the eastern border between Georgia and Florida. Head of the tide extends to rkm 88 and salt water extends to rkm 30-35. The St. Marys River is managed by the Georgia Department of Natural Resources (GaDNR) and the St. Johns River Water Management District (SJRWMD) in cooperation with St. Marys River Management Committee (SMRMC). The St. Marys River Management Committee (SMRMC) is a quasi-governmental advisory panel established by Interlocal Agreement between Baker and Nassau counties in Florida and Camden and Charlton counties in Georgia. The SMRMC has five voting representatives from each county: one county commissioner and four appointed members (two riverfront landowners or representatives of corporations with riverfront property and two at-large members). One representative from the St. Johns River Water Management District (SJRWMD) and one representative from the Georgia Department of Natural Resources (GDNR) serve as non-voting members.

1) Habitat Assessment

   All historic spawning and rearing habitat is still available. Neither has been quantified.

2) Threats
   a. GDNR Environmental Protection Division has identified a stretch of the lower St. Marys River with hypoxic summer conditions.
      i. GDNR has developed a TMDL for dissolved oxygen and is working with local governments and conservation organization to implement measures to reduce organic loads and improve dissolved oxygen conditions in the affected river reach.
   b. Florida Department of Environmental Protection has developed a water quality assessment as a road map for developing plans to improve water quality in the basin (FDEP 2007).

Ocklawaha River

The Ocklawaha River is the largest tributary of the St. Johns River but it does not have a documented historical spawning run of American Shad. It flows 119 kilometers from Lake Griffin to the St. Johns River and there is a dam located at rkm 19 that was constructed in 1968 (Senator George Kirkpatrick Dam). The Ocklawaha River is mentioned in this plan because some advocates for dam removal cite American Shad among the species of migratory fish that would benefit from removal of the dam.

Habitat above and below the dam appears suitable for American Shad to spawn. However, records of a spawning run of or fishery for American Shad from the Ocklawaha River have not been found. One specimen was noted in a dissertation entitled “Fishes of the St. Johns River System” (McLane 1955). There are anecdotes from veteran commercial fishermen of American Shad present in the Ocklawaha River prior to dam construction (Jordan 1994) but no confirmation. There are modern anecdotes of shad present below the dam but recent efforts to locate spawning American Shad in the Ocklawaha River below the dam have yielded none (Holder et al. 2012). The absence of a documented historical or current run of American Shad in the Ocklawaha River precludes a need for a restoration plan. However, the prospect of dam removal may warrant further investigation into whether shad historically used or could use in the future the Ocklawaha River.

The St. Johns River Water Management District produced an updated review (to update the 1994 review) of downstream water quality/nutrient loading in 2016 (Hendrickson 2016). The preliminary finding is that additional nutrient loading from a free-flowing Ocklawaha River is not likely a disqualifying factor for dam removal when balanced against other nutrient mitigation strategies ongoing in the watershed.

References

Dutterer, A.C., Allen, M.S., and W.E. Pine. 2011. Spawning Habitats for American Shad as the St. Johns River, Florida: Potential for Use in Establishing MFLs. Special Publication SJ2012-SP1. St. Johns River Water Management District. Palatka, FL.

FDEP 2007. Water Quality Assessment Report: Nassau-St. Marys. Florida Department of Environmental Protection, Division of Water Resource Management. Tallahassee, FL.

FDEP 2008. Basin Management Action Plan for the Implementation of Total Maximum Daily Loads for Nutrients Adopted by the Florida Department of Environmental Protection for the Lower St. Johns River Basin Main Stem. Florida Department of Environmental Protection. Tallahassee, FL.

FDEP 2010 (2019 amended). Basin Management Action Plan for the Implementation of Total Daily Maximum Loads Adopted by the Florida Department of Environment Protection in the Lake Jesup Basin. Florida Department of Environmental Protection. Tallahassee, FL

FDEP 2012. Basin Management Action Plan for the Implementation of Total Maximum Daily Loads for Nutrients and Dissolved Oxygen Adopted by the Florida Department of Environmental Protection in the Middle St. Johns River Basin for Lake Harney, Lake Monroe, Middle St. Johns River and Smith Canal. Florida Department of Environmental Protection. Tallahassee, FL.

FDEP 2017. Final TMDL Report Nutrient TMDLs for Crescent Lake (WBID 2606B) and Documentation in Support of Development of Site-Specific Numeric Interpretations of the Narrative Nutrient Criterion. Division of Environmental Assessment and Restoration Florida Department of Environmental Protection. Tallahassee, FL.

FDEP 2018. Deleon Springs Basin Management Action Plan. Division of Environmental Assessment and Restoration, Water Quality Restoration Program. Department of Environmental Protection. Tallahassee, FL.

FDEP 2018. Gemini Springs Basin Management Action Plan. Division of Environmental Assessment and Restoration, Water Quality Restoration Program. Department of Environmental Protection. Tallahassee, FL.

FDEP 2018. Volusia Blue Spring Basin Management Action Plan. Division of Environmental Assessment and Restoration, Water Quality Restoration Program. Department of Environmental Protection. Tallahassee, FL.

Gao, X. 2006. TMDL Report: Nutrient and DO TMDLs for the St. Johns River above Lake Poinsett (WBID 2893L), Lake Hell n' Blazes (WBID 2893Q), and St. Johns River above Sawgrass Lake (WBID 2893X). Florida Department of Environmental Protection. April 2006.

Gao, X. 2009. Final TMDL Report: Nutrient and Dissolved Oxygen TMDLs for the Six Middle St. Johns River Segments Between the Inlet of Lake Harney (WBID 2964A) and St. Johns River above Wekiva River (WBID 2893C). Florida Department of Environmental Protection. December 2009.

German, E.R. and J.C. Adamski. 2005. Hydrology and Water Quality of Lakes and Streams in Orange County, Florida. Scientific Investigations Report 2005-5052. US Geological Survey. 103p.

Hendrickson, J., Lowe E.F., Dobberfuhl, D., Sucsy, P., and Dean Campbell. 2005. Characteristics of Accelerated Eutrophication in the Lower St. Johns River Estuary and Recommended Targets, to Achieve Water Quality Goals, for the Fulfillment of TMDL and PLRG Objectives. St. Johns River Water Management District, Palatka, FL.

Hendrickson, John. 2016. Effects on Lower St. Johns River Nutrient Supply and TMDL Target Compliance from the Restoration of a Free-Flowing Ocklawaha River. Technical Publication SJ2016-1. St. Johns River Water Management District, Palatka, FL.

Holder, J., R. Hyle, and E. Lundy. 2012. ST. JOHNS RIVER AMERICAN SHAD INVESTIGATIONS COMPLETION REPORT, Fiscal Year 2006-2011. Freshwater Fisheries Research, Resource Assessment: Fish and Wildlife Research Institute. Florida Fish and Wildlife Conservation Commission, Tallahassee, FL, USA

Hyle, R, Marbury A, Lundy, E., and J.C. Holder. 2019. Saint Johns River Shad and River Herring Long Term Monitoring Annual Report. FY 2018-2019. Freshwater Fisheries Research: Fish and Wildlife Research Institute. Florida Fish and Wildlife Conservation Commission, Tallahassee, FL.

Jordan, F. 1994. Environmental studies concerning four alternatives for Rodman Reservoir and the lower Ocklawaha River (Volume 1 Executive summary & Volume 14 Ocklawaha River migratory fish assessment). St. Johns River Water Management District (SJRWMD), Palatka (PAL), FL. Available as a hardcopy

Kelly, M.H. and J.A. Gore. 2008. Florida river flow patterns and the Atlantic multidecadal oscillation. River Research and Applications 24 (5): 598-616.

Lowe, E.F., Battoe, L.E., Wilkening, P.E., Cullum, P.E., and T. Bartol eds. 2012. St. Johns River Water Supply Impact Study. St. Johns River Water Management District. Technical Publication SJ2012-1

Magley, W., and D. Joyner. 2008. TMDL Report: Total maximum daily load for nutrients for the Lower St. Johns River. Florida Department of Environmental Protection. June 2008.

McLane, W. M. 1955. The Fishes of the St. Johns River System. Doctoral Dissertation.Library University of Florida. Gainesville, Florida.

Miller, S.J., Brockmeyer, R.E., Tweedale, W., Shenker, J., Keenan, L.W., Connors, S., Lowe, E.F., Miller, J., Jacoby, C., and L. McCloud. 2012a. Chapter 12 Fish. St. Johns River Water Supply Impact Study. St. Johns River Water Management District. Technical Publication SJ2012-1

Miller, S.J., Brockmeyer, R.E., Tweedale, W., Shenker, J., Keenan, L.W., Connors, S., Lowe, E.F., Miller, J., Jacoby, C., and L. McCloud. 2012b. Appendix 12.C. Potential Withdrawal Effects on Anadromous Herrings. St. Johns River Water Supply Impact Study. St. Johns River Water Management District. Technical Publication SJ2012-1.

Paerl, H.W., Piehler, M.F., Carmichael, W.W., Dyble, J., Moisander, P.H., Leonard, J., and A. Waggener. 2002. Photoplankton and Zooplankton in the St. Johns River System: Factors affecting Community Structure and Function. Year 2 Final Report to St. Johns River Water Management Disctrict under Contract No. SD154RA.

Pinto, G., Bielmyer-Fraser, G.K., Goldberg, N., Ouellette, A., Le, A., Pyati, R., Zoellner, B., Closmann, C. (2019/20). 2020 State of the River Report for the Lower St. Johns River Basin, Florida: Water Quality, Fisheries, Aquatic Life, & Contaminants (LSJR). Prepared for the City of Jacksonville, Environmental Protection Board. https://sjrreport.com.

Rhew, K. 2020. Draft Report Dissolved Oxygen TMDL for Haw Creek above Crescent Lake (WBID 2622A). Division of Environmental Assessment and RestorationFlorida Department of Environmental Protection. Tallahassee, FL.

SJRWMD 2002. Middle St. Johns River Basin Surface Water Improvement and Management Program. St. Johns River Water Management District. Palatka, FL

SJRWMD 2007. Upper St. Johns River Basin Surface Water Improvement and Management Program. St. Johns River Water Management District. Palatka, FL.

SJRWMD 2008. Lower St. Johns River Basin Surface Water Improvement and Management Program Update. St. Johns River Water Management District. Palatka, FL.

USACE. 1973. Survey-Review Report on Central and Southern Florida: Project Econlockhatchee River, Florida. Jacksonville, FL: Corps of Engineers

USACE 2014. Jacksonville Harbor Navigations Study Duval County, Florida: Final Integrated General Reevaluation report II and Supplemental Environmental Impact Statement. U.S. Army Corps of Engineers, Jacksonville District. February 2014.

Williams, R.O., and G.E. Bruger. 1972. Investigations on American shad in the St. Johns River. Florida Department of Natural Resources Marine Research Laboratory Technical Series 66. 1-49.