Atlantic States Marine Fisheries Commission

Habitat Committee

November 3, 2015
World Golf Village Renaissance Resort
500 South Legacy Trail, St. Augustine, Florida

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.

Remote Access
Webinar: https://global.gotomeeting.com/join/262826293
Conference Call: Dial: **1-888-394-8197** and enter passcode **499811**

1. Welcome and Introductions (*J. Kritzer*)	8:00 a.m.
2. Committee Consent	8:05 a.m.
• Approval of Agenda	
• Approval of Proceedings from May 2015	
3. ACFHP Update (*L. Havel*)	8:10 a.m.
4. NE FL Estuarine Habitat Restoration: Marsh Madness! (*R. Brockmeyer*)	8:20 a.m.
5. Overview of Damariscotta Mills Dam Fish Ladder (*D. Wilson*)	8:50 a.m.
6. Discussion on 2016 habitat factsheets *(L. Havel)*	9:20 a.m.
7. Discussion on eel genetics: habitat factsheet (*J. Kritzer*)	9:35 a.m.
8. Break (15 minutes)	10:00 a.m.
9. Update: habitat bottlenecks paper (incl. tautog disc.) *(L. Havel, J. Kritzer*)	10:15 a.m.
10. FMP Amendment updates (menhaden, shrimp, tautog) *(L. Havel)*	10:45 a.m.
11. Lunch	11:45 p.m.
12. Review 2015 Work Plan (*L. Havel*)	1:15 p.m.
• Habitat Management Series Products (Sciaenid Habitat document) (*K. Smith*)	
• 2015 Habitat Hotline: Impacts of Energy Development on Fish Habitats (*K. Smith*)	
12. EDF Workshop Review *(J. Kritzer)*	2:15 p.m.
13. Break (15 minutes)	3:05 p.m.
14. Set 2016 Work Plan (*L. Havel and J. Kritzer*)	3:20 p.m.
• Discuss 2016 Action Plan	
• Discuss 2016 Habitat Hotline	
15. Other Business	4:40 p.m.
16. Adjourn	5:00 p.m.

Field Trip to Volusia Dragline Ditch Restoration Sites: Wednesday, November 4th, morning
Meet at hotel front lobby at 7 a.m. Vans will depart at 7:10 a.m.

Atlantic States Marine Fisheries Commission

Habitat Committee

April 22-23, 2015
Hyatt Regency Pier 66
2301 SE 17th St, Fort Lauderdale, Florida

Meeting Notes

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Field Trip: Palm Beach County - Grassy Flats Restoration Project
Wednesday, April 22
The field trip will take place during the morning (approximately 8:30 a.m. to noon).
Please stay tuned for details on transportation.

ASMFC Staff Present: Dr. Lisa Havel, Toni Kerns, and Melissa Yuen

Committee Members Present: Russ Babb (NJ), Lou Chiarella (NMFS-NE), Jimmy Johnson (NC), Wilson Laney (USFWS-SE), Gary Mahon (USGS, for Rachel Muir), Dawn McReynolds (NY), January Murray (GA), Cheri Patterson (NH), Mark Rousseau (MA), Eric Schneider (RI), Kent Smith (FL, chair), Marek Topolski (MD), Bob VanDolah (SC), and Dr. Pace Wilber (NMFS-SE).

Committee Members present via telephone: Penny Howell (CT)

[Babb, Laney and Smith, members, and L. Havel, ASMFC staff, joined the meeting late at approximately 1:45 pm due to dealing with rental van logistics]

Day 1: Wednesday, April 22 (1:00 p.m. – 4:30 p.m.)

Welcome and Introductions (*T. Kerns for K. Smith*) 1:00 p.m.

Committee Consent 1:05 p.m.

- **Approval of Agenda**
- **Approval of Proceedings from October 2014**

Review 2015 Work Plan (*T. Kerns*) 1:20 p.m.

Habitat Fact Sheets
Action item: The committee will submit a list of the top 3 species they are interested in updating for the habitat fact sheets. This is due to Lisa by May 26th.

Action item: Lisa will give the list of assigned fact sheets to the committee, and they will have two weeks to review and edit them before sending them back to Lisa.

- **Habitat Bottlenecks Whitepaper**

Melissa Yuen noted that there may not be bottlenecks for each species. Bob VanDolah noted that SCDNR doesn't believe that there is a habitat bottleneck for Weakfish, at least not in the southern part of the range. Marek agreed and indicated he thought that it was more of a predator-prey issue, for Weakfish.

Bob noted that we had discussed in the past having a species in the paper, like sturgeon, or American Eel, which had a more obvious habitat bottleneck. He isn't sure where all of that got lost in the process.

Kent asked if Jake Kritzer had a more recent version.

Toni stated not unless he had one that hadn't been shared yet.

Kent asked Melissa if we hadn't discussed sturgeon in the past. She indicated that we had done so.

Kent suggested that the document be completed, that we add sturgeon as a case history, if need be, then complete it.

Toni suggested that we check with Jake, to see if he is willing to continue as the lead. If he isn't, then we need to find a new lead. Pace stated that he would like to see no new material added to this document, after sturgeon.

We discussed the fact that we have already done the habitat sections for American Lobster and Atlantic Sturgeon. Pace suggested that we could take the completed Atlantic Sturgeon habitat section, and modify it for use in this document.

Pace noted that the horseshoe crab material was not in this version of the document. Toni pulled it up on the screen.

Bob VanDolah asked what the bottleneck was, for Horseshoe Crabs. Melissa and Wilson stated it was spawning beaches, they thought.

Marek questioned whether the bottleneck for Horseshoe Crabs was a current, or future concern.

Penny indicated that her understanding is that it IS a current bottleneck, at least according to the bird people.

Marek asked if the issue was reduction in the physical area of beach, or a reduction in the density per unit area. Penny wasn't sure that you could tease those two parameters apart.

Bob stated that in his mind, the issue was getting further muddied. Are the eggs limiting for reproduction, or for bird consumption. Penny stated that it is both issues. She guessed that the physical area was more important than the density. Bob noted that the ASMFC is trying to deal with the sustainability of the Horseshoe Crab population, not the birds.

Toni noted that the ARM model actually deals with both issues. The primary trigger for keeping the fishery open, Penny stated, is having enough Horseshoe Crab eggs for the birds.

Jessica Coakley noted that with regard to summer flounder, and having information available to determine whether there is in fact a habitat bottleneck, and that in relation to the stock, there is some strong linkage to certain habitats. Jessica wasn't sure that it was necessary to have a clear documentation of a habitat bottleneck, but she noted that she wasn't here during the early evolution of this issue.

Bob VanDolah noted that one of the concerns that Vince O'Shea had when he started this, is that there are some species for which factors other than fishing, are affected stock sustainability. Bob wasn't sure that we are helping the process, if we identify species for which there is not a clear linkage to a habitat bottleneck. American Lobster is a perfect example with a habitat bottleneck.

Jessica noted that Pacific salmon is a good example as well, she felt. But in some cases, it could be the management. She noted that all species probably have some potential habitat bottleneck.

Kent …………

Wilson noted that he was with Bob when they met with Vince to have this discussion, and Vince was the one who suggested Weakfish as the first species we consider. Wilson noted that Marek was certainly correct that predation may be a factor, especially with Weakfish at very low abundance levels, and Spiny Dogfish and Striped Bass at very high abundance levels. Wilson noted that predators are part of the "habitat," so he asked if that was a legitimate point to consider, i.e., predators present in the normal habitat of a species, constituting a habitat bottleneck because of high abundance. Bob and Marek didn't think that would constitute a habitat bottleneck.

Bob noted that American Lobster was a better example of a species with a valid bottleneck.

Lou stated that in his opinion, variables such as temperature or salinity were more the kind of thing that constituted habitat bottlenecks.

Kent noted that he didn't know enough about Weakfish to say whether there might be a bottleneck, or not.

Wilson noted that he was on the Weakfish TC but was certainly NOT a Weakfish expert. He noted that his understanding is that the Weakfish juvenile indices are doing just fine, the problem is in recruitment to the fishery. Wilson noted that we do have a new assessment model for the species in the works, that will incorporate environmental variables, so perhaps that would be a possible means for exploring whether a Weakfish habitat bottleneck exists, or not.

2015 Habitat Hotline

Melissa noted that adaptations to changing climate were one follow-up suggestion for the next newsletter issue. Kent noted that we would probably wind up with a lot of interest in more living shoreline, or other types of resiliency projects. He felt that would be a short article.

Bob indicated that he thought that we had a list of potential topics at one time.

Wilson suggested that we might want to address oil and gas exploration, and seismic-testing. He noted that would be rather timely in view of the present opening up of the south Atlantic for leases, and noted that Jessica and the MAFMC have done a lot of investigation of that topic.

Kent agreed that would be of interest in the south Atlantic. He asked for other ideas. One might be port expansion.

Toni noted that the NE Regional Council is going through spatial planning, and her understanding is that the SE Regional Council is getting ready to initiate their process. She wasn't sure that would be too hard.

Jessica stated that we could have several articles all related to ocean energy development, which could be broken into wind, G&G, and so forth. We could also introduce the Regional Planning Bodies. We could have a bunch of little modules that go along with it. All of the data portals also could be addressed. These could include the MARCO, and MARACOOS portals. They keep getting bigger and bigger.

Bob VanDolah thought that we did that sometime in 2013 or 2014. Bob asked Melissa if she recalled which issue it was in. Pace looked it up and stated it was Volume 1 of 2013.

Wilson noted that all the issues of the Habitat Hotline are now on the ASMFC website and thanked the staff for making that happen.

Jessica noted that the last issue was more focused on general ocean planning, so we could do one that focused on the new BOEM plan, and the activities that go along with the activity.

Wilson noted that we could do some updates on all of the energy activities, and advise readers what the current status is. We could also invite the two LCCs, SALCC and NALCC to let us know what they have been doing.

Bob noted that we could also invite Mary Conley of TNC to report on the TNC bottom mapping of the south Atlantic.

Kent agreed that was a great idea.

Bob thought that they may have put out some maps, already. Pace indicated that they are in the process of rolling out the information. Bob stated that they are still working on the metadata products and getting authorizations from all of the contributors. Bob felt it would be timely for the next issue.

Wilson suggested that we might want to request an article be done by some of the researchers who are putting acoustic tags in Atlantic Sturgeon, Striped Bass and other species. Wilson noted that there is a lot of data out there, from folks like Bill Post, Dewayne Fox, David Secor and others. He noted that he perceives that there are plans afoot to put some of this information in the peer-reviewed literature. He noted that the data from these fish will shed a lot of light on their habitat use and distribution, and enable us to better prepare our habitat sections of FMPs.

Bob Vandolah noted that the energy topic would be timely. He noted that with regard to Wilson's idea, we don't necessarily have to tie everything to energy, and he noted that it would be good to have some focus on new tools which we can use to track fish and determine their habitat use.

Melissa noted that she had put a document on the ASMFC shared drive that we can use to list proposed articles.

Bob asked if the last Habitat Hotline issue wasn't longer than 14 pages.

Toni indicated that it was, and that Tina and Melissa had to work hard to edit it down to a reasonable length. Toni noted that they may have to impose a word limit for individual articles.

Kent asked about the state updates. He felt that it was important to keep those in the document.

Toni noted that with it being electronic, it can contain links to other documents.

Kent started listing the articles: TNC mapping effort; seismic testing effects on habitat and species; LCCs—SALCC and NALCC.

Jessica explained that in water depths of 50 m or less, the impacts of seismic testing can be lethal, at least this is what is coming from anecdotal accounts from some scallop fishermen. Jessica noted that the sound can carry long distances, and can have a potential impact on benthic organisms. Jessica suggested that we have a general article on seismic testing.

We decided that Jay Odell would be the appropriate person to contact Mary Conley, since he also works with TNC. Bob noted that he was willing to contact Jay, if needed.

Action item: Jay Odell and Bob VanDolah will work together to contact Mary Conley about the TNC Benthic Habitat Mapping Effort announcing a web-based product (1/2 page) for the Habitat Hotline. A draft is due on September 1st to Kent and Lisa.

For the LCC article, Wilson agreed to contact Rua Mordecai of the SALCC; Dawn agreed to contact Megan Tyrell of the NALCC.

Action item: Wilson Laney will contact Rua Mordecai to write up an article for the Habitat Hotline concerning SALCC habitat prioritization tools in the marine/estuarine systems: information to inform the ocean energy exploration. A draft is due on September 1st to Kent and Lisa.

Action item: Dawn McReynolds will contact Megan Tyrell to write up an article for the Habitat Hotline concerning NALCC habitat prioritization tools in the marine/estuarine systems: information to inform the ocean energy exploration. A draft is due on September 1st to Kent and Lisa.

We had a discussion of whether the TNC work links to the SALCC Conservation Blueprint 2. Wilson thought it would link with the SALCC work; Pace stated it would not. He noted that the SALCC blueprint marine data were very sparse.

Wilson also agreed to make the contacts for the acoustic tagging article. He wasn't sure but thought that there may be a single POC researcher who he could contact, that would be willing to work with the other researchers and develop an article.

Action item: Wilson Laney will make contacts for the acoustic tagging article. This will be less than a page and will be due to Kent and Lisa by September 1st.

Action item: Jessica Coakley will take the lead on the seismic testing article. The seismic testing article should address overall G&G activities in the Atlantic; effects of seismic testing on fish and habitat; impact of acoustic sound on fish behavior and habitat use. Jessica will contact the BOEM folks, Brian Hooker and/or Jake. A draft of this article is due to Lisa and Kent by September 1st.

Bob VanDolah asked her to try to work in some information about the benthic impacts as well, such as the anecdotal accounts of dead scallops after seismic testing. Bob suggested that this should be the lead article.

Kent noted that there are organized groups in Florida who are advocating opposition to offshore oil and gas. Kent suggested that we have some information on the process.

Jessica noted that is something that BOEM came and talked to the MAFMC about; Wilson noted that they also came and talked to the SAFMC.

Bob asked if Kent wanted information on the general process, or just the seismic testing.

Kent noted that he was interested in hearing about the process in general. Kent noted that he wanted information on how the process works and when citizens can plug in to the process. He noted that they rely on their Coastal Zone Management (CZM) folks to come and ask them what they think.

Jessica noted that there are a lot of steps in the process, and CZM has the opportunity to comment at all the stages of the process.

Kent noted that in FL, CZM doesn't usually address offshore issues.

Pace noted that in SC, the CZM program didn't originally consider offshore impacts; but the legislature and agency did come to NOAA and asked for authorization to comment, and did receive it. Pace noted that there was a clear time window when they did need to get comments in.

Jessica noted that she has been working on the energy issues for the last months so the timing is good for her.

The article on the permitting components and public comments will be worked on by Jessica.

Kent noted that we should add the federal/state updates.

Bob suggested that the article on acoustic tagging be focused as a new habitat management tool, and not be linked to energy development.

Cheri noted that NMFS has a proposed rule out to expand Northern Right Whale Critical Habitat. Wilson noted that if we wanted to have an article on that issue, we should ask Barb Zoodsma of NMFS Protected Resources Division to write it.

Kent asked if we had every put any ESA-related articles in Habitat Hotline in the past.

We weren't sure. Toni noted that the Northern Right Whale Critical Habitat certainly has the potential to impact fishing and fisheries, and habitat in a secondary way.

Kent noted that some areas designated for kinetic energy, may become de-facto MPAs. Bob asked if operators could exclude activity in those areas, and was told they can.

Bob VanDolah suggested that we have a brief blurb in the Habitat Hotline that talks about habitat bottlenecks, and then has a link to the document, once we post it.

Eric Schneider noted that when Jason gave the presentation to the Habitat Committee, about the lobster habitat bottleneck, there were some really cool figures in that presentation. He suggested that we might be able to use some of those figures in the Habitat Hotline article, if appropriate. Eric noted that if we were going to use American Lobster as an example, we could use some of that material.

Bob noted that he was just thinking that some folks may not realize that there are habitat bottlenecks in the life history of certain species. Bob agreed that some of the figures may be useful.

Eric gave us examples of some of the figures that he was thinking of using, which showed that larval settlement was now not occurring in some areas.

Kent agreed that would be good, although any such maps would by necessity be very small. He noted that you could just make the point that lobsters are thermally-limited. Penny noted that this article is already written as far as she is concerned. Penny noted that the lobster stock assessment is due May 1st.

Kent asked if there was anything missing. He asked if we need to address alternatives to seismic testing, or solutions.

Wilson noted that his understanding is that there are alternative means of searching for oil and gas resources.

Jessica concurred that is the case. She mentioned instruments that can detect anomalies in the earth's magnetic field. She noted that the Council (MAFMC) has indicated that there may be mitigative measures as well, such as the seasonality of testing, and/or areas that are off-limits for testing.

Pace noted that anyone doing seismic testing has to have a "harassment" permit from NOAA, for marine mammals. He noted that only a few of the companies who have said they are interested, have applied for such permits. He indicated that he doubts the number of entities conducting testing will actually be as high as it now appears.

January asked about the use of air guns and "ramping-up" of the sound levels.

Jessica confirmed that was the case.

January asked about the grid sizes.

Pace indicated that his understanding is that the grid lines won't be very tight. He stated that the larger fish should be able to leave the area, but the smaller ones are more subject to impact, potentially. Jessica went into some detail about the grids and area to be covered.

Jessica indicated that she would also talk to the BOEM staff about alternative survey approaches as well.

Kent asked who would lead the issue, overall. Melissa indicated that we have to set up deadlines as well.

Kent asked for a volunteer to take general command of the issue. He noted that he didn't know much about this topic, but if it was just mostly making sure that the articles get in on time, he could do that task.

Melissa and Toni explained that the person would be assisting to put together the articles in a good sequence, and working with the coordinator to get all the articles in on time.

Kent volunteered to spearhead the effort.

Melissa noted that we can move the deadline up. In the past we have tried to have a decent draft by the October meeting, then the staff can do the editing and layout and publish it by the end of the year.

Kent suggested a September 1 deadline. Toni indicated that the same deadline would be used for the state paragraphs, and she will provide us word limits for the updates, and the articles. Kent suggested that perhaps each article be limited to a page.

Bob felt that the TNC article, with a map, shouldn't take up much space. He noted that the seismic-testing article should be longer. Bob wasn't sure that the LCC work was ready for prime time, and felt that it could be short. The management tool/acoustic-tagging article might be a little longer.

Wilson noted that he always tried to produce more than enough, and let the staff and coordinator edit to available space, rather than producing too little information and then having to produce more.

Action item: For the state updates, each Habitat Committee member will be responsible for their jurisdiction's update. Please send a draft report to Kent and Lisa by September 1st.

Action item: Bob VanDolah and Penny Howell will work on the lobster bottlenecks teaser for Habitat Hotline. A draft is due to Kent and Lisa by September 1st.

Action item: Jessica Coakley with work with BOEM for an article on the permitting components/public comments for Habitat Hotline. A draft is due to Kent and Lisa by September 1st.

Bob asked that Denise Sanger's name be added to the SC box.

Cheri asked about the Maine representative. Toni noted that they were trying to get someone designated. She will asked Pat Kelliher, or Terry Stockwell, about an assigned staff person.

Gary Mahon will be substituted for Rachel Muir, who is retiring from USGS.

Kent noted that we still have to do the ACFHP review, and the sciaenid source document, and the fish passage discussion.

3:34 pm: Kent asked that we take a ten-minute break.

3:53 pm: The meeting reconvened. Kent noted that we were going to go back to the ACFHP update.

ACFHP Update (*L. Havel*)

Lisa Havel gave the update (as she noted, for the two Habitat Committee members who were not present for the ACFHP meeting). Lisa reviewed the meeting activities [see the ACFHP notes for details]. She noted that we had several presentations at the beginning of the meeting. The first presentation was from Dr. Dave Gilliam, on Staghorn Coral nurseries and restoration. The second presentation was by Erin McDevitt, on marine debris. The last presentation was by Jeff Beal of the FL FWCC on Lionfish. Marek Topolski gave a presentation to the Steering Committee on ocean acidification and also addressed the impacts in estuarine settings. Jessica Coakley gave a presentation on the Mid-Atlantic Fishery Management Council's habitat activities. Jessica Graham gave an update on the activities of the Southeast Aquatic Resources Partnership. Steve Perry, coordinator of the Eastern Brook Trout Joint Venture, gave an update on the NFHAP initiative to create a fund to support projects, at the national level. The Steering Committee spent several hours reviewing the Strategic Plan and laying the groundwork for a new Implementation Plan. The Steering Committee also discussed the Conservation Strategic Plan for 2017-2021. George Schuler gave us an assessment of the work that the ACFHP has done to date, in completing all of the tasks in the plan. Julie Devers gave us an update on the projects that ACFHP has funded and hopes to fund in 2015. Julie also updated the group on the North Atlantic Landscape Conservation Cooperative Aquatic Habitat Assessment modeling being done for winter flounder. We also discussed the options available to use some of the remaining funding for work on river herring. Caroly Shumway updated the group on the National Fish and Wildlife Foundation (NFWF) River Herring Project, which is due to the NFWF by April 30. The project looked at six rivers along the US east coast, and entailed holding workshops to prioritize river herring habitat restoration in those watersheds.

Bob VanDolah asked when that final report would be out. Lisa noted it would be submitted to NFWF on April 30th.

Lisa noted that the North Carolina Coastal Federation was voted in as the 33rd partner in ACFHP.

Science and Data needs were discussed as well. Caroly led us in that discussion and the partnership will have further discussions. The decision was to focus on the species/habitat matrix, and also on creating a decision support tool.

Bob asked if minutes or a summary of that meeting would be available. Lisa noted that she would be producing minutes from Wilson's notes. Wilson noted that he would be glad to send a copy of his notes to Bob, recognizing that Lisa would be producing the official version.

Eric asked about the species/habitat matrix specifically. Lisa noted that the primary request she has been getting is to produce species maps, from the matrix. Marek noted that details haven't been discussed. Lisa noted that the spatial data haven't yet been compiled, that would show the species distribution.

Eric noted that he would like to see the maps.

Marek noted that George Schuler had indicated that he had a great GIS person who he could put on the task. Lisa noted that funding is a necessary.

Eric asked Bob about the mapping he had referenced that was done by TNC. Bob noted that it covers the area from Virginia, to the Florida Keys. Bob noted that the scale depends on the data. The maps are similar to the ones developed by TNC for the mid-Atlantic, and the northeast. The maps reflect the quality of the data used to create them, and are kind of all over the board. Bob noted that he has expressed concerns that some of the assumptions are too broad. He noted that he hoped they would write caveats.

Wilson noted that the NOAA Estuarine and Living Marine Resources (ELMR) program produced a series of reports on the species, by life stage, and seasons of occurrence, for all US estuaries. These are available online in pdf format, and Wilson noted that he has them on his hard drive. Wilson noted also that Dr. Ken Able at Rutgers, who recently wrote a book on the life history of fishes on the east coast, would be another good source of information about the distribution and habitat use of species.

Fish Passage Database

Kent reminded everyone to please send in information for this database. Jeff Kipp is the ASMFC staff person responsible.

Action item: All Habitat Committee members, please send in any pertinent fish passage data to Jeff Kipp (jkipp@asmfc.org).

Habitat Management Series: Sciaenid Habitat Source Document

Kent noted that some of the sciaenid species accounts are completed and will be going to the appropriate TC for review. Kent noted that Chip Collier had left the NCDMF, so it is uncertain whether we still want to try to include the kingfish species, or not. Wilson noted that the last time he talked to Chip at the last SAFMC meeting, he was still willing to work on that account, since he is doing his PhD. The key is the time lines, and having someone to review any text. Wilson asked about having the South Atlantic State-Federal Fisheries Management Board review it. Toni indicated that she didn't believe they would have the expertise. Wilson suggested that the Spot and/or Atlantic Croaker PDT could possibly review any text on kingfishes.

Kent asked Wilson if he was willing to contact Chip and verify his interest. He will do so, and will cc Lisa when he does so. The draft would have to be provided to ASMFC by the end of July, so a complete sciaenid source document draft could be done and ready by October.
Action item: Wilson Laney will contact Chip Collier and verify his interest in continuing to write the weakfish section of the sciaenid source document. He will cc Lisa when he does. A draft is due by the end of July.

We discussed other source documents. Kent and January thought that we had made a list at some point in the past. Kent noted that Marek is working on an aquaculture source document. Bob noted that he would like to see that one completed before we begin any new ones.

Action item: Marek Topolski will give finished aquaculture document to Lisa by end of July.

We looked at our list, and there wasn't any logical grouping of other species, that could be a new source document. Toni recommended that we avoid any of the jointly-managed species, since those all have EFH designations and therefore already have very good accounts of habitat requirements.

Kent asked about tautog. Toni noted that the Board is planning to do an update on tautog, so the timing would be good for an updated FMP habitat section. We discussed who might be able to do such a section. It was suggested that Jeff Tinsman would be a good possibility. Melissa mentioned Paul Caruso. We thought that even though Paul is retired, he might have some interest. Melissa noted that Jason McNamee from RI also knows a lot about tautog. Toni stated that we should not ask him for any additional work, since he has been doing all of the Atlantic Menhaden work.

Kent asked again if we had a list of potential source documents. Melissa stated that we didn't. She noted that we had begun work on updating the existing living shorelines document. Lou noted that we had one conference call on that task. He noted that there are a number of other documents, such as one from NOAA, which might serve our purposes.

Kent noted that Florida is also working on a public web site for living shorelines, which will be up and running in May, and that will be a good resource.

Melissa noted that Kent was probably thinking about the Habitat Management Series of documents list that we had made. He was.

Lou asked to what extent the habitat sections of FMPs were accessible. Kent noted that they are for the most part embedded in the FMPs.

Toni noted that she thought that the Habitat Committee was trying to develop habitat management goals and objectives which could be implemented not necessarily by the agencies, but by partners in collaboration with the agencies.

Lou noted that he was talking about the actual habitat science. He noted that sometimes web sites constitute a real maze. Toni noted that was why we put together the species fact sheets.

Wilson noted that Lou was correct about the habitat sections and life history information being embedded in the FMPs. Wilson noted that the American Shad Habitat Plans were the first effort of which he was aware to put recommendations in one place, by river systems for a given species. His FWS colleague Larry Miller had served on the American Shad PDT and had worked with other members to develop the outline for the Habitat Plans. They had hoped that jurisdictions would come up with specific recommendations for restoring American Shad habitats within each jurisdiction and/or major spawning river, but that didn't happen for all of the plans. Some of them do have specific recommendations, others don't. They all do have very useful information about American Shad habitats, so that is an additional source of information for that particular species.

Eric noted that it would be good to have a road map or table of some sort that would key to the most current habitat information for each species. Wilson thought that was an excellent idea. He noted that we might want to pull out the habitat section for each species and post that on the ASMFC web site.

Break (10 minutes)

Habitat Considerations for Ecosystem-Based Fisheries Management (*T. Kerns*)

Kent gave a brief background for this topic. He noted that the original Ecosystem Based Management (EBM) work group hasn't met for a few years. Shanna had come and talked to us about Habitat Committee involvement in the discussion of EBM. Kent noted that the Biological and Ecological Reference Points (BERP) work group is working on ecological reference points. He asked Wilson to comment on the potential for Habitat Committee involvement.

Wilson suggested that Toni give us an update first, since he thought that she had talked to Pat Campfield and/or Shanna Madsen and received an update on where things are with regard to EBM in the commission.

Toni noted that she had talked to Pat Campfield. He noted that back in 2003-2004, the Management and Science Committee had produced a white paper, on how the ASMFC could more toward EBM. She noted that the ASMFC does have a Multi-Species Virtual Population Assessment (MSVPA), which includes a number of species. The MAFMC is also moving toward forage fish management, with a view toward not developing any new fisheries for such species, without having sustainable management. The ASMFC is trying to determine how to be engaged in this. The MAFMC is proposing to use either the Bluefish FMP, or the Squid-Mackerel-Butterfish FMP, as a vehicle. Also the NEFMC is working on some EBM-related work. Toni noted that they are trying to stay on top of all of this. They are trying to consider what the Habitat Committee could provide to the Policy Board, as the Councils move forward toward EBM. Perhaps that is something that we could pose to the Policy Board, which is what could we provide.

Wilson noted that all of the Councils are moving in this direction. He noted that he would suggest that the Habitat Committee request presentations on what the two federal agencies, and the three Councils, are doing in this regard. He noted that there is at least one case where an Ecopath/Ecosim model is being used for management advice (article in the January issue of Fisheries, on the pink shrimp fishery in the southern Gulf of Mexico). Wilson agreed that we should ask the Policy Board what they believe we need to provide.

Toni noted that we need to provide some fodder to the Policy Board, for their consideration.

Eric asked if we need to provide the Policy Board information on habitat capacity, or what. Should we just consider EBM and not any interim step?

Toni thought that there may be some commissioners who have some level of understanding about EBM, but there may not be enough of them who fully understand the needs or the process, outside of the Atlantic Menhaden Management Board.

Eric wondered about having some information presented to us at the annual meeting.

Toni wondered if we might have a focus on the fall meeting, on this topic. Toni noted that there was some possibility that the Policy Board may not be ready to move in this direction.

Kent noted that we might just begin to stock our own war chest, to get ready to have this discussion. He noted that if you are looking for suites of organisms, or finding habitat bottlenecks, this might be a place to go.

Eric noted that if we are moving from the habitat matrix, to maps, and looking at species distribution, that might be useful

Kent suggested that we have a path forward. We can send invitations to the Councils to provide presentations to us. Kent asked if the Commissioners would be able to attend.

Toni noted that is a problem. They have discussed having the Habitat Committee meeting separately, so members like Cheri and Wilson who sit on the management boards, would not have to miss the meeting.

Kent wondered about doing an evening symposium, for an hour or so, on this topic. Maybe hold it to an hour or so.

Lisa asked whether we might be able to tack the Habitat Committee meeting on the end of the week. Toni noted that the Policy Board would have come and gone already, and it is hard for ASMFC to justify having Habitat Committee members there for longer than just the Habitat Committee meeting. She noted that it might be difficult to have the bosses approve weekend travel.

We discussed the evening option again. Toni noted that there will be some event going on every evening during the annual meeting, except for Wednesday. Also there are always other conflicts. Toni indicated that maybe there is a day when the meetings are ending earlier, when we could squeeze it in. She will talk to Bob Beal about it.

Action item: Toni Kerns will talk to Bob about scheduling a brief (~1 hour) symposium by Council members on EBM during a day where the meetings end early at annual meeting.

Bob VanDolah noted that we are still early in the process. In his mind, it is all up in the air. He thought it would be great to have commissioners come in and listen to the same presentations, but if they can’t, at least the Habitat Committee will be moving forward. Commissioners may want to step out of their other meetings and at least hear what is being said about their regions.

Toni asked who in the New England Fishery Management Council (NEFMC) is the point of contact (POC) for the NEFMC ecosystem work. It is Lori Steele. Lou noted that their SSC is involved and they also have a committee. Melissa indicated that they have just put together a new committee.

Kent noted that Jake Kritzer will be the chair of the Habitat Committee, in the fall. He noted that we need to elect a new vice-chair tomorrow and noted that January Murray has indicated an interest in serving in that capacity. Kent asked everyone to think about that overnight, and then we can have that election in the morning. He asked if anyone had to be at the airport early. Cheri stated that she has to be at the airport at 1:00. Kent suggested that we have the vote in the morning.

Bob wondered if Jake would be unavailable, due to his new EDF duties. Kent acknowledged that Jake is very busy. He suggested that we cross that bridge, when we come to it. Russ suggested that we have that discussion, AFTER we elect January as the vice-chair.

Kent noted that we do need to have one more discussion. He noted that Melissa has moved to CA, Los Angeles. Melissa will no longer serve as the coordinator, and Lisa Havel will step in to see if she can serve both ACFHP and the HC, at least through October (**it is actually Sept. 1st*). Kent noted that he has discussed this with Lisa, and we will monitor this closely to make sure that her ACFHP duties are not impacted. He noted that he talks to her about ACFHP on a daily basis. Lisa has assured him that she views this as an important opportunity.

Cheri told Melissa that we would have a drink for her tonight. Melissa said to have two. She was asked to contact Steven Spielberg while she was out there.

Kent thanked Melissa for all of her efforts on behalf of the HC and wished her the best in her new role. Kent asked Melissa if she would be with us tomorrow.

Toni noted that HC members would have breakfast in this room at 8:00 am.

Kent suggested that we meet at 6:30 pm in the lobby. The thought was to walk somewhere for dinner.

Other Business 5:18 p.m.

No other business was discussed on this day.

Adjourn Day 1 5:18 p.m.

Day 2: Thursday, April 23 (8:30 a.m. – 12:00 p.m.)

[NOTE: Same members were all present for the second day of the meeting; including Penny on the telephone, once we got her connected.]

Reconvene 8:30 a.m.

Kent reconvened the meeting. We briefly discussed rides to the airport.

Kent noted that we needed to do a couple of important things right off the bat. He noted that we need to elect a vice-chair. He noted that January Murray had volunteered to serve in that capacity. Jimmy Johnson nominated January. Cheri Patterson seconded the nomination. Wilson moved nominations cease and we elect January by acclamation. The motion was seconded by Bob. The motion passed and January was elected. Kent noted that she will be working with Jake Kritzman for the next couple of years, before she has to take over the "throne."

Kent recognized Mark Rousseau for his report.

Artificial Reef Committee Update (*M. Rousseau*) 8:35 a.m.

Mark gave the report via a PowerPoint presentation. The Artificial Reef Committee (ARC) meet in Clearwater, FL, and HC chair Kent Smith was also in attendance. Mark noted that he had given a report on a Massachusetts shoreline protection project, using complex reef habitat. The project has multiple partners, including the Corps of Engineers. As of today, the contract between NFWF and MADMF has not been finalized. They aren't sure what the holdup is.

James Ballard with the Gulf States Marine Fisheries Commission gave an update on the invasive Lionfish Management Plan. The plan was published in July of 2014.

Jeff Tinsman gave an update on the status of Special Management Zone (SMZ) designation for Delaware's artificial reefs in the EEZ. The reefs are largely funded by Wallop-Breaux funds and there are penalties if the sites are not managed to eliminate conflicts between recreational and commercial stakeholders. As of January, 2015, NOAA-Fisheries has prepared appropriate documents to have these SMZs approved.

Erik Zlokovitz gave a presentation for Bob Martore (SC) on plans to deploy stainless steel subway cars as reef materials. There have been issues in the past with pieces breaking off these cars and then being caught in dragging gear, a good distance away. Some of these reefs have other materials, including reef balls. Deployment has been with and without oyster spat.

Kent Smith presented the ACFHP funding opportunity through the MAFMC, and Executive Director Chris Moore. The project may consist of an artificial reef somewhere in the mid-Atlantic. The ARC discussed existing substrate in the mid-Atlantic as being cobble deposited by glaciers, but such substrate is not well-documented. Mark noted that Lisa may have more details. He noted that talks are ongoing and there has been some discussion of using an existing site, to minimize any permitting issue. The ARC will continue to work with ACFHP on this project. A subcommittee was set up to deal with this project.

January Murray gave a presentation on GA oyster reef restoration. GA has established test plots to test conditions at various sites. GA uses a logic model as part of this testing.

Pete Simard gave a presentation on boat visitation rates from acoustic detections on paired artificial-natural reefs on the West Florida Shelf. He has used acoustic technology to record boat visitation. This allows seasonal comparisons. A web link was provided to the presentation http://flseagrant.ifas.ufl.edu/artificialreefs/Simard.pdf.

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[8:46 am: We had a brief interruption here due to a hotel engineer fixing the call-in line for us.]

Chris Stallings gave a presentation on integrating basic and applied ecology using paired artificial-natural reef systems. Mark noted that there is a link to the presentation, on the slide http://flseagrant.ifas.ufl.edu/artificialreefs/Stallings.pdf.

The ASMFC and GSMFC are updating the Guidelines for Marine Artificial Reef Materials and the guide will be posted on the web, once revised.

Erik Zlokovitz of MD had given a presentation on helping fisheries managers and the general public understand the production-attraction effects of artificial reefs. The public needs to understand that reef conditions vary from one region to another. Mark noted that this information should be available on the web as well.

The location for the next meeting was discussed. Galveston was one option, but Mark noted that the location would actually probably be somewhere in FL.

Mark asked for questions.

Bob asked about the need for Delaware SMZs, and asked if it was mostly a commercial conflict issue. Yes, it is because Wallop-Breaux requires that reefs funded be managed for recreational use.

Kent noted that it was good to see the ARC getting involved in oyster reef construction and restoration, and also good to have them engaged in our discussion of the MAFMC and ACFHP potential project. Kent noted that some of the captains he knows have become very vociferous about wanting more habitat available. Kent noted that there seems to have been a change in philosophy about dropping just any materials.

Pace asked if the ARC had discussed the management of offshore oil rigs in the Gulf of Mexico, as artificial reefs. Eric asked if he meant decommissioned rigs. Yes, Pace did. Mark noted that the LA representative gives an update each year, regarding which rigs have been decommissioned and which are being removed. Mark asked Pace to be more specific.

Pace noted that there was some controversy some years ago about designation of decommissioned rigs as EFH. He thought that there was supposed to be some further discussion of the issue.

Mark noted that it is frequently discussed, but for EFH, it is a species-by-species discussion. It wasn't discussed.

Pace asked if ASMFC had given any sort of habitat designation, for artificial reefs. Wilson didn't believe that we had given them any sort of designation.

Pace noted that the SAFMC EFH designation does include artificial reefs.

Mark noted that each of the states have different approaches. AL for example allows private individuals to have sites which don’t have to be publically revealed. Mark noted that would seem to preclude their designation as EFH.

Pace noted that he is not aware that any of the south Atlantic states issue permits for private citizens to dump materials for artificial reefs.

Kent noted that there are some provisions in FL, for designating sites on which materials can be placed by private individuals. These are large areas.

Bob asked if that wouldn’t conflict with commercial trawling. Kent advised yes, that happens. There are issues with this. Kent noted that there are issues in AL all the time, in part depending on how much material is used. Kent noted in that part of the world, Red Snapper is king, and the tackle shops even sell materials which can be used to attract Red Snapper.

January noted that off GA, their reefs are designated as SMZs, and are also designated by the Council as EFH-HAPC. She was confused as to when the designation would come into play. She asked Pace to clarify.

Pace noted the designations are what they are. They are EFH under the Snapper-Grouper FMP. Pace noted that the Council designations are deeply hidden in their web site. Some folks who use the site only deal with the summaries, and those don’t list artificial reefs. You do see some folks who take the position that artificial reefs aren’t EFH. There are some artificial reef managers in the south Atlantic who are not aware that the Council has made these designations.

Pace noted that he can provide the text for January if she wants.

Kent noted that FL does use the designations, and reference them, but they don’t make the call as to what that means. He noted that NOAA does the EFH consultations.

Kent noted that Marek had an issue he wanted to bring up, with Mark, regarding Chris Stallings work. Kent noted that Homeland Security, around some of the military bases, uses technology which tracks boats that intrude on the military boundary, and enables them to set up an intercept. Kent noted that may be helpful in terms of getting data. He has seen the maps and that is pretty neat. Kent noted that the ARC may be interested in this. This might be a good way to secure more data. Kent wasn’t sure that you could tell vessel size using this technology. He wasn’t sure that Chris had information on vessel time on the reefs. It is an interesting management tool.

Marek noted that MD managed to get a 5.6 million dollar grant in 2003. They have established a system of cameras and radar units, in the Bay, around bridges, and also at boundary areas around important resources, such as oyster reefs. Whenever there is a boundary encroachment, the patrol boats receive an alarm, and then the vessels can be monitored. This has been used to catch watermen with undersized oysters, and so forth. The system has been used heavily for enforcement. The MD DNR gets monthly updates and finds lots of violations this way. Marek noted that the monitoring can be used for anything and everything of concern, such as keeping boats out of controlled areas, like the Chesapeake Bay Bridge-Tunnel. Toni pulled up the web site and showed us a vessel track within a closed area.

January asked for clarification of the diagram.

Marek explained that the red area on the screen was the closed area, so the dotted line shows the vessel track.

Eric asked what they are actually using to track the vessels. It is a combination of cameras and radar. They have an agreement with MD that the state can use it for fisheries enforcement, as well as for safety concerns.

Kent noted that for five million dollars, you too can have this kind of system.

Mark clarified that the system had gone live in 2003. Marek confirmed that was the case and noted that it catches fishing violators, both commercial and recreational, monthly.

Eric asked how big the area on the diagram was. Toni noted that the scale bar was 500 feet. She noted that most states don't actually use such a system. She noted that MD may actually get some of the money that comes from violation fines, to support the system.

Marek read one example to us of how the system was used to catch some oyster poachers. If they are found guilty, they face an $8,000 fine.

Jimmy noted that is a lot more than fines would be in NC. That was an expensive two bushels of oysters.

Eric noted that was really cool, but didn't think that RI could afford it. He noted that they are doing a lot of oyster restoration in RI, and they are doing it in closed waters. There is a fear that someone may harvest oysters from that area, then get sick and that could result in closing down legal areas. They have been looking into remote camera systems. They are studying them to see if they are feasible. They are also expensive. Eric noted that it would be really hard to get a vessel into some of these sites, so if you see someone there, it is likely that they would be illegally harvesting.

Marek noted that MD gets all of their natural resource cases heard in court, on the same day, and that has helped to get the cases heard without complications from other sorts of cases.

Kent noted that in FL, if you are taking shellfish with intent to sell, technically you are potentially violating public health laws, and could be guilty of a felony. He noted that one of his uncles used to catch barracuda, filet them, and sell them as grouper, and folks could have gotten ciguatera. His uncle had asked him to help him get out of tickets, and Kent said that he was instead going to turn him in. He noted that this activity constituted public endangerment. Kent noted that this had happened in NJ.

Russ noted that he was involved in that case. It took five years of his time, but five folks went to jail for their activity. They were illegally selling oysters. Russ noted that the public health aspect of it was a big deal. Bob noted now Kent understands why he wouldn't order the green mussels last evening.

Kent noted that there are some areas that would lend themselves to this technology. He noted that they are aware that people are going in and harvesting oysters from closed areas.

Mark noted that in MA, protected areas are near urban areas, so those are susceptible to illegal harvest, because they are sited in closed shellfish areas.

Kent noted that it is interesting how different states approach the issue.

Marek noted that it is important to point out that the system is used heavily by the USCG and for public safety.

Wilson noted that he will take this information about this technology to the SAFMC Law Enforcement Committee. He asked Marek if fixed structures are required to host the cameras and radar. He wondered if this method could be used for monitoring the SAFMC HAPCs.

Action item: Wilson Laney will take the information about the technology discussed during the Artificial Reef section to the SAFMC Law Enforcement Committee.

Kent noted that he will make sure that Chris knows about the system.

Kent noted that we have about an hour left before the break, and asked if we wanted to discuss other business.

Wilson returned to our EBM discussion of yesterday. He noted that he had sent out the pink shrimp paper we had discussed yesterday. We also had further discussions about the role that the Habitat Committee could play, as ASMFC moves toward EBM. Kent noted that he and Wilson had talked about manatees, and carrying capacity. We will be discussing this in the future.

Kent asked Wilson to brief the Habitat Committee on the North Topsail Island beach filling project. Wilson and Pace briefed the group on the project. Wilson noted that the Habitat Committee may want to consider requesting ASMFC sending an informational letter to the Corps regarding this project.

Pace noted that there is a whole lot we don't know. Pace noted that NMFS has no EFH issue, but they are happy with the fact that the Wilmington COE district temporarily shut the project down, and are closely monitoring the project. Pace noted that there are other reasons that the project is way behind schedule. Pace noted that the Town got money to allow the dredge to go away, and then remobilize in the fall. Pace noted that should the Town of Topsail Beach decide, they can follow that course of action. Pace stated at this point, to him, there isn't a lot of clarity regarding the issue. Pace stated that a larger issue is that more and more, along the SE coast, especially in NC, SC and GA, the ancient vibracore samples being used to characterize the sand materials, are not adequate. There are a lot of projects moving forward without adequate information to characterize the sediments. Also, in many cases especially in NC, mining of the inlets is proposed, and NMFS would rather see the mining done offshore. They would rather have offshore mining.

Kent asked if NMFS was moving forward with trying to develop some better protocols. Pace was not aware that they are.

Bob VanDolah noted that at Folly Beach, there were lots of vibracore samples, but during the middle of the project, they began spewing out coquina rock. The dredgers tend to ignore the depth specifications in the permit, if they are using a pipeline dredge. The SCDNR encourages shallower and wider cuts, and that may be more expensive than deeper dredging over a smaller area.

Kent indicated that is sounded to him that we need to have a better protocol for the sampling.

Bob indicated that there are two problems. In SC, they are running out of sand, so having to go to offshore resources. In Folly Beach, they don't know where they will find the sand. Part of the problem there is that USFWS maintains that dredging can't happen in a Coastal Barrier Resources Act (CBRA) zone.

Wilson asked if everyone knew what the CBRA was. Not everyone did, so he explained CBRA to everyone. It was passed by Congress with the intent of removing any federal subsidies, such as flood insurance, from any undeveloped barrier island habitats. The idea was that this would prevent or at least diminish the development of habitats for which there was a high risk of flooding or overwash. The Act has had mixed results.

Toni noted that in view of the sensitivity here, any letter would need to go through Commission Chair Dr. Louis Daniel and the Policy Board.

Wilson agreed that this one is rather tenuous, so perhaps instead of a letter on this project, we could prepare a letter from the HC that would focus on 1) the inadequacy of sediment sampling; and 2) the dredgers not adhering to depth and area limitation.

Kent suggested that be tied to ASMFC species, and Wilson and Pace agreed.

Pace stressed again that they were satisfied with the EFH aspect of the North Topsail Beach project. He noted that the vise they were afraid they would be caught in, was a two-week requirement for response, from the NMFS Protected Resources Division. Pace stated that he thinks the FWS is now not going to do a BO, but it also appears that the Corps will not allow the extended work period.

Bob VanDolah noted that the project looks like a moonscape and he is amazed that the dredging wasn't immediately halted. Jimmy had sent some photos around and Toni pulled those up to allow everyone to view them.

Kent noted that a general letter would probably be more appropriate.

Wilson volunteered to take a shot at drafting a generic letter to address the sampling issue, and the dredging compliance issue. Kent suggested that we keep it rather generic.

Wilson, Pace with anonymous assistance from certain other member will provide draft text for consideration.

Action item: Wilson Laney will work with Pace Wilber on a draft *generic* letter to address the sampling and dredging compliance issues discussed at the meeting. It should reference ASMFC-managed species. The draft will be sent out to HC and ASMFC staff for review by June 15th. The draft with edits will be sent to the Policy board in August for their consideration.

Wilson noted that he would get on his soapbox for one more comment, and that is that he has been approached by multiple commissioners, about why ASMFC has not been taking a position on more habitat issues. Wilson noted that it does take time for ASMFC to work with NMFS and FWS staff to prepare such letters and send them through the approval process.

Pace stated that it isn't an issue with the Council process, or with the two federal agency staffs.

Wilson agreed and noted that the Commissioners are the ones asking.

We agreed that Wilson and members will prepare a draft by June 15. That will be sent around to the HC and ASMFC staff for review, then taken to the Policy Board in August for their consideration.

Break/Hotel Check-Out (25 minutes) 10:00 a.m.

Kent reconvened the meeting at 10:25 am. He noted that Pace is to talk to us about the Port Everglades project. Kent noted that the hotel is technically part of the port. Wilson wanted to know why we are staying here. Kent said to ask ASMFC.

Port Everglades: Impacts and Mitigation for Coral and Seagrass (*P. Wilber*) 11:00 a.m.

Pace provided a PowerPoint presentation to us. Pace indicated that he had a 20-minute presentation for us on the mitigation for the project, just for the coral and hard bottom. He noted that there is also mitigation for seagrasses, but that part doesn't have as much of a feel-good ending.

In July, 2012, the President identified seven critical infrastructure projects which would be expedited to modernize and expand five ports. There is lots of pressure to move these projects. Four of the five identified ports are in the south Atlantic: Charleston, Savannah, Jacksonville and Miami. Pace noted that he used to work for the Corps and spent some of his time there mapping habitats.

Pace noted that most of his talk would focus on the Port Everglades project. The Final Environmental Impact Statement (FEIS) recommended plan was for deepening the main turning basin to 50 feet below MLLW; extend the turning basin 300 feet; widen and deepen South Access Channel; deepen Turning Notch to -50 feet MLLW after local sponsor dredges to -42 feet MLLW; deepen the Outer Entrance Channel (OEC) to -57 feet MLLW widen OEC to 800 feet; and extend OEC seaward 2,200 feet. Pace noted that the project will require the elimination of existing very successful mangrove mitigation. Pace noted that the federal EIS avoided getting bogged down in local mitigation issues. Pace noted that he would focus on the impacts from widening the Outer Entrance Channel.

Pace noted that there is a reef tract that extends all the way up to Martin County. Over the last 15 years, there has been a lot of effort expended to map and characterize this habitat. He noted that there is a lot of information on the resources associated with the proposed project. Pace showed us a map of the proposed project, which will entail widening and extending the OEC. There is an inner, mid- and outer reef. Pace indicated the outer reef to his knowledge is in pretty good shape. Surrounding the dredging footprint is a "halo" 150 meters wide, which is the allowable mixing zone for state water quality standards to be met. Not meeting this standard requires securing a variance.

The Coral Reef Impact Assessment indicated that there will be 17.51 acres of impact, including: 10.58 acres of high quality outer reef; 86,000 stony corals; 71,000 octocorals; 2.9 acres of sedimentation and rubble "avalanche;" monitoring to verify coral below -57 feet MLW; 109 acres of coral within 150 m of the channel. Pace noted that the numbers of colonies vary, depending on whose data you use. The total number of colonies could be as high as 200,000+ colonies.

Pace explained how the 2.9 acre figure was derived for the sedimentation and "rubble avalanche." There will be fracturing in the reef structure itself, which will cause more of the reef to fall apart. NMFS did an intense analysis for the EIS. The Corps was willing to mitigate upfront for ten percent of the estimated 5+ acres which NMFS estimated would be impacted. Pace noted that they are concerned about sediments being suspended during the dredging and impacting the 109 acres of coral within the buffer zone. In both the "halo" and "avalanche" area, there will be monitoring to verify the acreage that the Corps has agreed to mitigate, up-front. If monitoring reveals wider impacts, the Corps will have to mitigate more.

Wilson clarified that he had correctly captured the mitigation requirements. Pace indicated he had done so. January clarified that the 17.51 acres will be destroyed. Pace confirmed it would be destroyed.

Pace explained that he would provide a summary of two years' worth of discussion. The general mitigation approach will be to create artificial reefs, using boulders put on bare bottom, or areas augmented with rescued corals. They can also enhance natural hardbottom by outplanting nursery-raised corals. The criteria for selecting sites include: UASCE policy compliant; cost; presumed acceptability by the State of Florida. The Corps has committed to remove 11,500 coral colonies and move them. Pace noted that they are not aware of anywhere in the world where anyone has agreed to move this many colonies. So, the Corps is going way beyond what anyone else has done. They agreed to plant corals at the same density they are found in the area from which they were removed. When you do the math, you get the acreage values.

January asked what the success rate is for transplanted corals? It varies. It could be less than this, but if they are properly moved, the success rate can be as high as 90 percent.

Pace noted that the three criteria caused a lot of Corps compliance and cost issues. The measures have to be compliant with the Corps policies and fall within their cost effectiveness requirements. Pace noted that this required a long uphill battle. Pace noted that there was an agreement early on that the Corps would coordinate everything with NMFS ONLY, then would take the plan to everyone else. Pace noted that there was a lot of staff-to-staff coordination during the process.

Pace noted that he would not dwell on the nursery-raised corals. That was one early issue, since the Corps wasn't aware of this process and how well the nurseries were already working. Pace noted that it turns out that the species most easily-raised in the nursery, is in fact Staghorn Coral (for all the reasons Dave had shared with us earlier in the week). The other side of the use of that species is that Staghorn is a listed species. The Corps doesn't believe that federal civil works projects should be funding Recovery Plans. The Corps sent out a policy memo during the middle of negotiations for this project. Sixty to seventy percent of the corals to be moved, were Staghorn. This looked and smelled like a Recovery Plan project to the Corps' headquarters, which they had just told the District not to participate in. Pace noted that it took months and months to get this across to Corps headquarters. It was less of an issue with the Jacksonville District and South Atlantic Division.

Pace noted that the corals will be raised in both land- and water-based nurseries. They will be spread around to minimize the risk of loss from hurricanes or other factors. Pace showed us some photos of areas planted in 2006, as they looked in 2013.

Cheri and Russ asked what percentage of the corals to be planted come from the project area. Pace noted that the Staghorn Coral to be used in the project will not come from the project area, but other parts of Broward County.

The NMFS used Habitat Equivalency Analysis to determine how much mitigation was appropriate. Pace noted that this tool is used by their Natural Resources Damage Assessment (NRDA) staff and the tool has been tested in court. The alternative is to use the Florida UNAM method, but that one is rather weak for corals. It is possible that it might be superior to HEA, but they had to make a choice and move on. The tool uses the time period, shapes of curves, and economic factors in its analysis. Pace noted that this is another one of the areas where Corps policy, and NOAA policy, differed. Pace noted that the Corps thought that their policy was based on an OMB policy, of using zero percent, but the NOAA policy used three percent. In the final analysis it didn’t make much difference.

The analysis shows that boulders by themselves act as a fish attractant device, but the colonization of bare boulders takes a long time. At fifty years, only fifty percent has been colonized. The NMFS feels that is a pretty generous number. The red line in the graph shows the HEs for boulders plus transplants. The blue line represents reef enhancement through outplanting of nursery-raised corals. In theory, you could get this line from any coral you used, but since Acropora is more three-dimensional, you get a faster rate initially.

Pace showed us a graph of USACE proposed boulders as initial mitigation types. The graph is from a study that Dave did, which compares an artificial reef constructed by the Corps years ago, to species composition on the reef at Port Everglades. If you look carefully, you see that what is on the boulder reef in Miami, are fast-growing species which are not as beneficial, while the ones at Port Everglades are more beneficial. Pace noted that this data assisted in convincing the Corps that their numbers were wrong. Pace noted that one sponge species, which is important, does not appear in the boulder reef, but is present in the Port Everglades habitat.

The final Coral Reef Mitigation Plan includes: 5 acres of boulders; 2.03 acres with 11,500 rescued corals; 2.97 acres bare; 18.21 acres of coral reef enhanced with 103,000 nursery reared corals (6 to 10 years); enhancement sites will be 1/8 to ¼ acres; monitored for 3 years; this was presented as a draft mitigation option in the draft EIS and the recommended mitigation option in the final EIS. The species will include octocorals as well as the barrel sponge. Pace noted that the outplanting will occur in several cohorts, but he doesn’t have a slide to show that process.

Pace indicated that in the end, using the service area years, coral reef enhancement is providing most of the HEs generated for the project. The bare boulders provide only five percent of the mitigation value. The per unit cost is for coral reef enhancement. This analysis begs the question of why we are even bothering with the boulders. The reason is that folks are comfortable having the boulders there. If you look at it from a strictly economic perspective, enhancement is a better way to approach coral mitigation.

Pace concluded: coral reef enhancement with nursery-raised coral colonies yields more ecological services than boulder artificial reef (savings of 15.4 million dollars); EFH mitigation can address ESA issues. Next steps: refine mitigation monitoring, performance measures, and adaptive management plan; finalize environmental monitoring plan for assessing indirect impacts (lessons learned from Port of Miami). Pace noted that the EFH mitigation requires the offset of some of the ESA requirements, and that was a difficult point to get across to Corps headquarters. The NMFS will have to work closely with the Corps, once Congress authorizes the project, to prepare a detailed plan. They don't have a final monitoring plan to cover the "avalanche" effect. They do have a general idea about how they are going to do it. Pace noted that we are all aware of what has happened at the Port of Miami. Pace gave us an unofficial briefing on what has happened there. Substantially more impact than projected has occurred in the area adjacent to the channel dredging. The Corps hired NMFS to use divers to move Acropora in the affected area, for later outplanting. Pace noted that we can see the whole site, using Google Earth, including historic images. Pace noted that the Corps is being sued regarding these impacts. The NMFS is not a named party in the lawsuit, but they are involved in it. All of this is reported in the New York Times.

Pace noted that the Corps is very concerned that they get Port Everglades done correctly. They are dealing with their own crisis in Miami, but they are committed to work with the NMFS to finalize the mitigation plan. Pace noted the Corps' commitment to mitigation for ten percent of the corals in the buffer zone, is something that they have not done elsewhere.

Bob had a couple of questions. He asked from where the boulders will come. Pace noted that the Corps has not identified the source of those. They are optimistic that the boulders will come from the area to be dredged. Bob asked where the boulder field will be placed. The Corps hasn't identified the location yet, but they have identified the needed characteristics. That is another nitty-gritty issue that has been punted to the final plan. Bob noted that as Pace said, there has never been a transfer of 11,500 corals in the past. Is there some contingency if they can't move all of those? Pace stated that the credit from the HEA is to move those colonies. Pace stated they don't know how the cost will be affected. They think that the Corps has overestimated the cost of moving the corals. Pace noted that right now, the Corps is calculating the costs of nursery divers, as distinct from divers used for the relocation work.

Wilson asked if the HEA analysis used production in the existing areas, over future time span, and compared it to future production from the mitigation sites. Pace indicated it does. Wilson noted that based on his experience with other types of mitigation, he is skeptical that we would ever get full compensation in terms of ecosystem services, from the proposed mitigation. He stated again that he believes "mitigation" is just an administrative construct that we humans have dreamed up to make ourselves feel better about trashing our planet. Wilson noted that one of his graduate student colleagues at North Carolina State University had studied created salt marshes, years after their establishment, and documented that they still had not achieved the levels of production of natural marshes.

Kent noted that Penny Hall, at FWRI, has done some work on mitigation areas and he believes that she has found the same thing, which is that mitigation areas don't usually replace the ecosystem services that they are intended to replace.

Kent……………..

Pace noted that it is hard to find someone who has the clout to make commitments for multiple federal agencies. Pace noted that no one is actually in charge of all the players.

Wilson asked if Kent could share Penny's work once it is published. Kent noted that he would definitely provide the information to us, and would in fact see if he can get some preliminary information from her.

Kent thanked Gabby for coming up from Marathon, at 4:30 am this morning. She is giving a presentation on behalf of Tom Matthews, which documents the damage to hard corals from lobster traps. Kent noted that this may have application to other east coast pot fisheries. He noted that they thought it would be interesting to provide some perspective.

Effects of Lobster and Stone Crab Traps on Marine Habitats of the Florida Keys (*Gabrielle Renchen*) 11:30 a.m.

Gabby noted that she would focus on their lobster trap work, and how they have worked with the fishermen through cooperative research. The lobster fishery is one of the most valuable in FL. The 2013-2014 season had 561 fishermen, and there were potentially 480,776 trap certificates. The season harvested almost 5.79 million pounds, worth 30-50 million dollars. Much of this is due to the live market demand from China. The price usually begins lower and gets higher throughout, but for the last season the price remained high throughout.

Gabby noted that the fishery extends from Miami down through the Keys, but she will focus on the Atlantic side of the Keys. They did a survey along nine transects, and took video of the trap sites they found. Thirty-seven percent of the traps were in seagrass, 36% on bare substrate, 15% in algae, 9% on hardbottom, and 3% on coral.

Uhrin et al. (2005) did a study of traps left in seagrass for 1-24 weeks. There was shoot loss after 4-6 weeks. Thalassia exhibited recovery after 6 and 24-week trap soak. But Syringodium showed no recovery. The soak times were relevant to fishing practices. Soak time is usually less than 5 weeks. The main concern is therefore traps that are lost.

Only about three percent of the traps were placed in coral habitat. A trap hauling study was done by Lewis et al. (2009). They surveyed 44 traps by measuring injuries near the traps, returned the traps after pulls, and measured new injuries and injuries under traps.

The study showed that species affected were coral, fire coral, gorgonians, and sponges. There were 3.3 injuries per trap. Injury state was studied: 34 percent recovered; 60 percent persisted; and 6 percent worsened.

Trap movement was further studied. They followed 292 traps. Habitat were nearshore hardbottom (4 m depth), reef (8 m), reef (12 m). There were ~18 wind events per fishing season, with average speeds of 21 kts, duration of 4.8 days. Some were tropical cyclones, and the majority were cold fronts.

Gabby addressed the coral reef damage from wind events. Factors evaluated were linear distance moved (177 observations, 26 events, mean of 3.21 m, range of 0.5-4.2 m); area affected (34 observations, 7 events, mean of 2.88 m2, range of 0.4-3.9 m2); and sessile organisms percent cover affected (covered 51% of control and 41% of trap path).

In nearshore hardbottom, the traps moved a lot further (linear distance = 168 observations, 32 events, mean of 3.63 m, range of 0.7-110 m; area affected = 121 observations, 23 events, mean of 4.66 m2, range of 0.4 – 37.5 m2; sessile fauna percent cover was 12.9% for control, 2.4% for trap path).

Summary: seagrass, typical soak times are unlikely to cause long term harm to seagrass; lost traps damage seagrasses; effects varied by seagrass species. Coral reef-trap hauling: about 1720 m^2 (0.17 ha) of reef fauna injured annual by trap hauling. The numbers get larger when you consider trap movement: 38 ha of reef and 2490 ha of hardbottom had loss of living fauna caused by traps moved during high winds. These are chronic impacts which are happening every lobster-fishing season.

They then tested 23 different trap/buoy/line/bridle configurations. All the changes were made to the standard wooden trap design.

Most of the changes had no effect in reducing trap movement. A few had small but non-significant effects. The Spongex Buoy was too expensive. Increasing the amount of concrete made the traps too heavy. Toni asked Penny Howell how heavy American Lobster traps are. They are 60-70 pounds, she thought.

The corner bridle did not work with the hauling gear used by the fishermen.

They worked with the fishermen to try nine different trap designs. They investigated factors like reducing wood, increasing wire, different trap shapes, and adding legs to the traps. Increasing wire did reduce movement, different shapes had no effect, and adding legs reduced movement but was not practical.

Fishermen did select four modifications which did reduce trap movement: wire basket; wire on frame; vertical wood; and a wire trap. The four new designs were tested, with the standard trap, for movement. In nearshore bottom, the wire basket moved 16 percent as much as the standard trap, the wire on fram moved 24% as much, vertical wood moved 73%, and the wire wrap moved 80% as much.

In the coral reef habitat, the wire basket actually affected more area than the standard traps (130%); the wire wrap affected 142% more.

So, to summarize trap movement data: wood replaced by wire reduced trap movement on nearshore hardbottom habitat; modifying traps did not reduce movement in coral because of structural complexity of habitat; fishermen perceived vertical wood trap design as a feasible design. Gabby noted that the state has not yet made any management changes. Using wire poses a number of additional issue, such as greater persistence and greater bycatch. The fishermen thought that the vertical wood design was the best one.

Bob asked if the regulations allow traps to be placed in coral habitat. Yes, they do, but there are some closed areas in the FL Keys NMS, and in Acropora Critical Habitat.

Russ asked about biodegradable panels. Gabby noted that the wooden traps are all considered biodegradable. The wooden traps can ghost-fish for a year, and wire traps for longer.

Kent asked what sort of staples are used. They used steel staples.

Mark asked if there are estimates of the trap loss rate. Yes, and they are getting ready to publish that information. Gabby indicated in a good year, they report 18 percent loss, which is about 18,000 or so traps. In a really bad year, the loss rate can be up to 50 percent. They have some data from marine debris surveys, which estimate over a million non-fishing traps, and a bunch of fishing ones as well. Mark stated that he guessed they would want to maintain wooden traps in the fishery as long as they can.

Gabby indicated that was correct. They do have a trap recovery program, but many of them are missed. Usually they only find the ones with buoys. The first ten or so traps recovered are waived.

Pace asked if they have looked at blue crab traps. Gabby indicated that her lab has not looked at those. Kent indicated there is a trap retrieval program for blue crab pots as well. He noted that it varies around the state, but they used the TX loss rate of ten percent. There was no rotational closure, but now they rotate the closed period. There is a two-week closed period during which anyone can pull any traps they find. There can also be organized derelict trap removal, but those have to be permitted through FWCC. Groups can go do this in problem areas.

Pace asked if they move a similar distance. Gabby noted that hasn't been done. They hope to do studies on stone crab and blue crab traps.

Wilson asked about the economics of possibly using pingers on the traps. Gabby noted that the traps themselves cost about fifty dollars per trap. She suspected that fishermen would not be amenable to using pingers.

Kent…………………

Gabby……………………..

Russ Babb noted that they did a pilot study in Great Bay. There were a lot of traps that piled up and were removed during the Hurricane Sandy cleanup.

Toni asked Penny Howell to comment. Penny stated that the old-fashioned lobster traps used in the Gulf of Maine are rounded, so they don't flip over. She asked Gabby if they had tested a rounded design. Gabby didn't think a rounded design had been tested.

Kent noted that the traps are made rectangular for purposes of stacking. Penny noted that you do have to stack them vertically. Penny stated that weight again as 50-60 pounds.

Kent noted that in the spiny lobster fishery, the traps are "baited" with short lobsters, because they are a social species. The American Lobster traps use dead bait. Penny noted that for centuries, the Gulf of Maine American Lobster fishery has used the rounded design, to eliminate movement.

Jimmy asked about the type of line used on the traps. Gabby noted that weak links are required, but the line type can vary. Kent noted that often floating line is used. He noted that during the season, there are buoys all over the place and sometimes it is hard to avoid them.

Jimmy noted that the blue crab fishermen in NC are required to use sinking weighted line, in order to keep the lines under the water and avoid complaints from boaters, and also avoid gear loss.

Kent noted that pot fisheries are not only found in the Keys. He noted that the bycatch in the Spiny Lobster fishery is limited, but sometimes large fish do get in the traps. He noted that it is good for the fishermen to be amenable to working with the agencies to modify the gear.

Jimmy asked how comfortable they were with the original estimates of the numbers of pots in the water.

Kent said that for the last 30 years, there has been some sort of certification/registry program. Jimmy asked if Mike Orbach hadn't worked with FL on this issue. Kent wasn't sure.

Gabby noted that last year was a really good year. Kent noted that the virus had dropped the harvest by a good amount, so it was good that last year was a good one. Kent noted that the fishermen don't quite get that the higher the number of pots, the lower the CPUE. He noted that makes good business sense to him. He noted that the reductions were pushed back every year. Gabby noted that now, the number is reduced only when a fisherman sells traps to someone outside his family.

Jimmy noted that in NC, fear of pot reductions to come, caused fishermen to inflate their numbers, back in the 1990's.

Wilson asked if Gabby could update us on the proposed closure of Biscayne Bay NP. He noted that the South Atlantic Fishery Management Council received presentations from both NPS and Bill Kelley, at recent Council meetings, regarding the proposed closure. He wondered what was happening with that issue. Gabby noted that she has not been involved in that issue, noting that I should pose the question to her boss. Kent noted that boaters and fishermen definitely always have opinions about these proposed changes, so their commissioners usually get involved.

Kent asked about getting the presentations up on line, and about Melissa's tenure. Toni noted that she would work with Lisa on providing the ASMFC staff support for the Habitat Committee.

Wilson asked about our membership. He noted that our EPA representatives haven't really been attending. Also, he asked where we were on finding a Corps representative to replace Doug Clark.

Pace had followed up on one suggestion and that Corps person had retired. We all agreed it would be beneficial to have a Corps representative on the HC.

Bob noted that it would be good to have an appropriate representative. Pace agreed and noted that it may be appropriate to have someone from ERDC, or from the Corps' dredging division.

Bob asked that we check into the DE representation. Kent and staff will follow up on that task.

Action item: Lisa Havel will work with Toni Kerns on updating the Habitat Committee membership.

Eric noted that Susie Avasian from EPA had also noted that travel funding was an issue, but that doesn't affect their phone participation. Eric stated that he thought Susie was a good choice for EPA representation.

Mark thanked Kent for his good work as chairman of the HC. Kent noted that he would enjoy NOT being a chairman and looks forward to working with Jake, who will be taking over as chair. He also thanked Toni for stepping in for Melissa, and for setting up the meeting location. Toni noted that it was a team effort.

Kent noted that the spring meeting was officially over and he hoped that we would have safe travels.

Other Business 12:15 p.m.

Other business was addressed earlier.

Adjourn Day 2 12:20 p.m.

Action items

Page 1

Action item: The committee will submit a list of the top 3 species they are interested in updating for the habitat fact sheets. This is due to Lisa by May 26th.

Page 2

Action item: Lisa will give the list of assigned fact sheets to the committee, and they will have two weeks to review and edit them before sending them back to Lisa.

Page 5

Action item: Jay Odell and Bob VanDolah will work together to contact Mary Conley about the TNC Benthic Habitat Mapping Effort announcing a web-based product (1/2 page) for the Habitat Hotline. A draft is due on September 1st to Kent and Lisa.

Action item: Wilson Laney will contact Rua Mordecai to write up an article for the Habitat Hotline concerning SALCC habitat prioritization tools in the marine/estuarine systems: information to inform the ocean energy exploration. A draft is due on September 1st to Kent and Lisa.

Action item: Dawn McReynolds will contact Megan Tyrell to write up an article for the Habitat Hotline concerning NALCC habitat prioritization tools in the marine/estuarine systems: information to inform the ocean energy exploration. A draft is due on September 1st to Kent and Lisa.

Page 6

Action item: Wilson Laney will make contacts for the acoustic tagging article. This will be less than a page and will be due to Kent and Lisa by September 1st.

Action item: Jessica Coakley will take the lead on the seismic testing article. The seismic testing article should address overall G&G activities in the Atlantic; effects of seismic testing on fish and habitat; impact of acoustic sound on fish behavior and habitat use. Jessica will contact the

BOEM folks, Brian Hooker and/or Jake. A draft of this article is due to Lisa and Kent by September 1st.

Page 8
Action item: For the state updates, each Habitat Committee member will be responsible for their jurisdiction's update. Please send a draft report to Kent and Lisa by September 1st.

Action item: Bob VanDolah and Penny Howell will work on the lobster bottlenecks teaser for Habitat Hotline. A draft is due to Kent and Lisa by September 1st.

Action item: Jessica Coakley with work with BOEM for an article on the permitting components/public comments for Habitat Hotline. A draft is due to Kent and Lisa by September 1st.

Page 10
Action item: All Habitat Committee members, please send in any pertinent fish passage data to Jeff Kipp (jkipp@asmfc.org).

Action item: Wilson Laney will contact Chip Collier and verify his interest in continuing to write the weakfish section of the sciaenid source document. He will cc Lisa when he does. A draft is due by the end of July.

Page 11
Action item: Marek Topolski will give finished aquaculture document to Lisa by end of July.

Page 13
Action item: Toni Kerns will talk to Bob about scheduling a brief (~1 hour) symposium by Council members on EBM during a day where the meetings end early at annual meeting.

Page 19
Action item: Wilson Laney will take the information about the technology discussed during the Artificial Reef section to the SAFMC Law Enforcement Committee.

Page 20
Action item: Wilson Laney will work with Pace Wilber on a draft *generic* letter to address the sampling and dredging compliance issues discussed at the meeting. It should reference ASMFC-managed species. The draft will be sent out to HC and ASMFC staff for review by June 15th. The draft with edits will be sent to the Policy board in August for their consideration.

Page 28
Action item: Lisa Havel will work with Toni Kerns on updating the Habitat Committee membership.

Report

Current Biology

RAD Sequencing Highlights Polygenic Discrimination of Habitat Ecotypes in the Panmictic American Eel

Highlights

- Despite panmixia, the American eel has ecotypes specific to rearing habitats
- These ecotypes are genetically distinct
- The defining traits are polygenic, and 331 loci most prominently distinguish ecotypes
- Functional annotation reveals many of these loci are within genes relevant to ecology

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In Brief

The American eel is a panmictic species that inhabit drastically different environments. Pavey et al. show that freshwater and brackish/saltwater ecotypes have a polygenic basis and are the result of repeated intra-generational mechanisms.

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Current Biology
Report

RAD Sequencing Highlights Polygenic Discrimination of Habitat Ecotypes in the Panmictic American Eel

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SUMMARY

The two primary ways that species respond to heterogeneous environments is through local adaptation and phenotypic plasticity. The American eel (*Anguilla rostrata*) presents a paradox; despite inhabiting drastically different environments [1], the species is panmictic [2, 3]. Spawning takes place only in the southern Sargasso Sea in the Atlantic Ocean [1]. Then, the planktonic larvae (leptocephali) disperse to rearing locations from Cuba to Greenland, and juveniles colonize either freshwater or brackish/saltwater habitats, where they spend 3–25 years before returning to the Sargasso Sea to spawn as a panmictic species. Depending on rearing habitat, individuals exhibit drastically different ecotypes [4–6]. In particular, individuals rearing in freshwater tend to grow slowly and mature older and are more likely to be female in comparison to individuals that rear in brackish/saltwater [4, 6]. The hypothesis that phenotypic plasticity alone can account for all of the differences was not supported by three independent controlled experiments [7–10]. Here, we present a genome-wide association study that demonstrates a polygenic basis that discriminates these habitat-specific ecotypes belonging to the same panmictic population. We found that 331 co-varying loci out of 42,424 initially considered were associated with the divergent ecotypes, allowing a reclassification of 89.6%. These 331 SNPs are associated with 101 genes that represent vascular and morphological development, calcium ion regulation, growth and transcription factors, and olfactory receptors. Our results are consistent with divergent natural selection of phenotypes and/or genotype-dependent habitat choice by individuals that results in these genetic differences between habitats, occurring every generation anew in this panmictic species.

RESULTS

Genome-wide Association and Data Verification

We collected genetic samples from yellow and silver eel life stages at eight locations each of freshwater and brackish/saltwater habitats that have known phenotypic differences (Figure 1) in the Atlantic Canada and St. Lawrence River regions (Figure S1). We then performed a high-resolution genome-wide association study (GWAS) with restriction-site-associated DNA markers (RAD tags) and used a multivariate approach to reveal genetic variation association with these ecotypes. Overall, we found a subtle genetic basis for the differences between the ecotypes in the form of co-varying allele frequencies in many genomic regions.

Out of the 42,424 SNPs initially considered (Table S1), 331 SNPs in 325 different scaffolds were found to be significantly associated with rearing phenotype in a random forest analysis (Figure 2; Table S2). We performed this analysis on a subset of 15,331 markers that were most variable by sampling site (see the Supplemental Experimental Procedures for details). The "out-of-bag" correct assignment was 89.6%. Nothing close to this percentage was achieved when individuals were randomly assigned to ecotype (200 datasets, mean correct assignment: 48.4%; Figure S2). Moreover, using a jackknife procedure, we predicted the individuals of the excluded sampling site with a mean accuracy of 91.2% ± 6.9% (Figure 3). There was significant genetic differentiation when only the 331 random forest SNPs were considered (analysis of molecular variance [AMOVA]; Fct = 0.017; $p < 0.001$), which is in contrast to the absence of significant differentiation between ecotypes when considering all markers (AMOVA; Fct < 0.001; $p = 0.317$), confirming panmixia as previously reported [2]. Yet, the allele frequency differences at each of the co-varying 331 random forest SNPs were modest (Δp mean ± SD = 0.0342 ± 0.0022), as expected by quantitative genetics theory for differences between polygenic traits [11].

Of the 331 associated markers, 55% ($n = 182$) are nearly fixed in one ecotype. This occurred in the freshwater locations with 137 markers (mean freshwater minor allele frequency [MAF] = 0.0027 ± 0.0083) and in the brackish/saltwater locations for 45 markers (mean freshwater MAF = 0.0016 ± 0.0061). We refer to these subsets as freshwater and brackish/saltwater modules, respectively. The fact that the freshwater module is three times larger than the brackish/saltwater one suggests that more genes

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Figure 1. Phenotypic Differences between Freshwater and Brackish/Saltwater Ecotypes

Two sexually maturing female American eels were captured in the St. Lawrence River during their spawning migration en route to the Sargasso Sea. The large eel is representative of the slow-growing, late-maturing (>20 years) ecotype that characterizes the Lake Ontario-Upper St. Lawrence River, the numbers of which are in steep decline. The small eel is representative of the brackish/saltwater ecotype, which is fast growing and early maturing (about 5 years) and this individual is the result of a transplant of young eels from the Atlantic coast to Lake Ontario in an attempt to mitigate the decline of eels in that region. Contrary to conservation goals, the transplanted individuals did not exhibit the phenotype that characterizes the receiving region. Photo by Guy Verreault, used with permission.

are influenced by intra-generational directional selection and/or genotype-dependent habitat choice in this ecotype.

Functional Annotation

Of the 331 SNPs most important in discriminating the ecotypes, 99 SNPs were associated with 101 annotated protein-coding genes (exon or interior intron) from the American eel genome (S.A.P., unpublished data) that blasted to Swissprot and were associated with unique gene IDs (Table S2). Of these, seven were in exons, one occurred in the 3′ UTR (30S ribosomal protein S18; rs18), and the rest were in interior introns. Of the seven mutations that occurred in exons, five were non-synonymous. The remaining unique 91 divergent SNPs were in interior introns and most likely involved or linked with *cis*-regulation [12]. One of the five SNPs that caused a non-synonymous mutation was Myosin light chain kinase 3 (Mylk3). It was completely fixed in the freshwater ecotype (e.g., a minor allele not found in a single freshwater individual). This gene has been demonstrated to be important for early heart development in vertebrates [13]. The polymorphism is found in the eighth exon, downstream of the conserved ATP binding and active sites. Another non-synonymous mutation was found in an olfactory receptor (O52D1) [14]. It has been suggested that olfaction plays a role in migration for both American and European eel, especially during migration to rearing areas [15, 16].

Based on the Gene Ontology (GO) analysis of the protein-coding regions of these 331 SNPs, there is a pronounced over-representation of developmental GOs: respiratory system development (GO: 0060541; p = 0.003), cardiac muscle tissue development (GO: 0048738; p = 0.008), and limb bud formation (GO: 0060174; p < 0.001) (Table 1). There is a wealth of migration and locomotion differences between these ecotypes. In the extreme case of the Lake Ontario-Upper St. Lawrence River, these freshwater rearing have more than 1,300 additional kilometers to travel during their migrations in both directions. Also, many freshwater individuals need to swim against the current to reach their rearing areas, whereas brackish/saltwater eels can rely more on selective tidal transport [17]. This suggests that energetic and locomotion costs that differ greatly between ecotypes are reflected in the genome and GO terms that define the genetic differences.

The freshwater module subset is characterized by enrichment of transcription factors (GO: 0033276; transcription factor TFTC complex p = 0.0008) and calcium ion binding (GO: 0005509; p = 0.0031) (Table 1). Specifically, the Urinary transporter 2 (Ut2) gene is a possible adaptation to the transition from freshwater back into saltwater during the spawning migration. Though most fish excrete ammonia directly through the gills, Ut2-mediated urea transport may be essential for the freshwater-to-saltwater transition, and the gene has been found to be highly expressed in gill tissue under these conditions in the American eel [18]. The SNP found in this gene was fixed in the freshwater ecotype, which would be the only group assured to experience such a fresh to saltwater transition.

The brackish/saltwater module subset is enriched in growth factor receptor binding (GO: 0070851; p = 0.001), positive

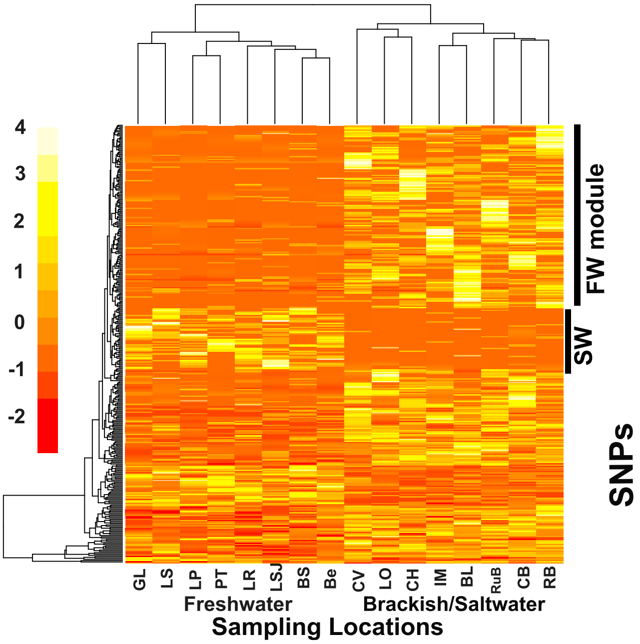

Figure 2. Sample Location Allele Frequencies for the 331 Most Important SNPs to Distinguish Eel Ecotypes

This heatmap illustrates the allele frequencies for all 16 study sampling sites. Each row represents a specific SNP, and each column represents a sampling site. Sampling site acronyms are defined in the map (Figure S1).The colors represent normalized (by row) allele frequencies. Half of the markers are nearly fixed in one ecotype and comparatively variable in the other. We designate SNPs exhibiting this pattern as either freshwater (FW; 137 SNPs) or brackish/saltwater (SW; 45 SNPs) modules and consider them separately. The LO location is freshwater, but we considered it to be a brackish/saltwater on the map because it is the result of brackish/saltwater-transplanted individuals. See also Figure S1.

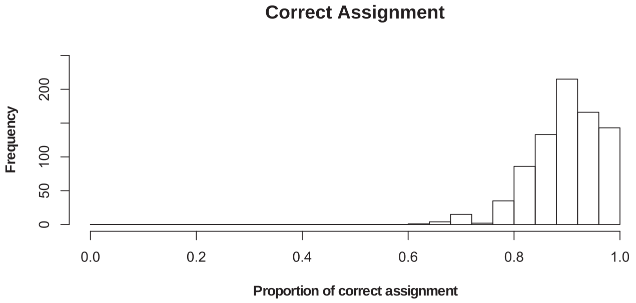

Figure 3. Proportion of Correct Ecotypic Assignment in the Jack Knife Procedure

For each iteration, all individuals from a single sampling location were excluded from the random forest analysis of the remaining 15 locations. Then, the results were used to predict the excluded individuals' ecotype. The success rate was 91.2% ± 6.9%. See also Figure S2.

regulation of chemotaxis (GO: 0050920; p = 0.0005), and respiratory system development (GO: 0060541; p = 0.003) (Table 1). One specific gene of interest in this module, vascular endothelial growth factor A (*VEGFA*), is essential for blood vessel formation (both vasculogenesis and angiogenesis). It has also been found to play a role in red blood cell formation in zebrafish [19].

DISCUSSION

Causes of Parallel Genetic Differences Despite Panmixia

We found consistent genetic differences that correlate with habitat ecotypes in the American eel. Though there has been conflicting evidence of panmixia versus subtle population structure in the European eel [3, 20–23], panmixia in the American eel is definitive with both nuclear and mitochondrial markers [2, 3]. This begs the question, which mechanisms could be acting in each generation that would result in consistent genetic difference between habitat ecotypes that are sufficient for 90% successful blind assignment? We propose that two possible mechanisms are (1) genotype-dependent habitat choice and (2) intra-generational spatially variable selection.

There is empirical evidence that European eel (*A. anguilla*) glass eels (young juvenile life stage) make choices based on salinity differences in controlled choice experiments [24]. In addition, a recent study with the American eel found that glass eels did make choices based on salinity in a controlled setting (migrated from brackish water to either salt or freshwater when given a choice between saltwater, freshwater, or remaining in brackish water) [9]. However, the proportion of choice groups did not vary by the two origins tested, the St. Lawrence (the most upstream glass eels known, thus more likely to become the freshwater ecotype) versus Canadian Maritimes (proximate to abundant marine ecotype eels), and there was no difference in growth among choice groups. There were, however, growth differences between origins independent of salinity choice [9]. Also, in an effort to restore Lake Ontario-Upper St. Lawrence abundance, glass eels from the Maritimes were transplanted to these locations [25]. This forced movement resulted in the transplanted individuals growing fast, with a substantial proportion becoming males compared with the historically slow growth and near absence of males [26], as well as assessed natural upstream migrants to the area [8]. Thus, eels do have the capacity to choose salinity habitats, and if these choice groups in nature are genetically different, this mechanism has the potential to result in the genotype-habitat associations that we observe.

The second mechanism that could result in the observed pattern is spatially variable selection. Indeed, selection has now been empirically demonstrated to be associated with a latitudinal and temperature gradients in the American eel [27–29], as well as in the sister species, the European eel [30]. Thus, the empirical evidence indicates that spatially variable selection occurs in both species of Atlantic eel. In contrast to the clinal variation associated with these studies, the drastic differences in salinity, biotic interactions, and flow regime in our studied ecotypes may represent stronger selection, making spatially varying selection acting on the freshwater-saltwater axis even more plausible. Mathematical modeling efforts also indicate that within-generation selection can result in differences in quantitative traits, even in panmixia (see the Supplemental Discussion for more details) [31–33]. In the large-scale transplant (see above), the eels grew fast, matured early, and out-migrated at a young age [34]. Given that eels from that area have the longest migration back to the Sargasso Sea, it is unknown whether the transplanted young eels would have the energy reserves for the spawning migration. Thus, their fitness cannot be evaluated.

Although we cannot rule out or definitively support either of the two hypotheses regarding the mechanism (or their interaction), we do demonstrate that there are polygenic genetic differences between the ecotypes that are sufficient enough to correctly reassign them blindly to their habitat of origin. This is complementary to the phenotypic plasticity known to occur in the species [35] and other recent studies indicating differences in reaction norms to salinity levels among sampling locations differs [8, 9]. We cannot rule out or support the presence of sex-specific strategies. The mechanism of sex determination is unknown in *Anguilla* sp. but is thought to partially or completely involve plasticity [8, 36, 37]. Similar to all GWAS approaches, the genetic differences are only correlated with the ecotypes. Moreover, the 331 SNPs are certainly not comprehensive, as we used RAD-tag sequencing, which is a reduced representation of the genome. Also, some quantitative genetic difference may be too subtle to detect with any current method [11].

More generally, assuming that these associated genetic differences underlie the phenotypic difference between the ecotypes, these findings illustrate theoretical expectations that the genetic basis of quantitative phenotypic traits is manifested as polygenic at the genomic level [11]. Despite the emphasis on examples containing genes of major effect accounting for phenotypic variation in nature [38], quantitative traits are expected to involve many genes of minor effects; thus, subtle shifts in allele frequency should be the expected mechanism underlying polygenic selection. This has recently been demonstrated for salmon survival at sea [39] and coral thermal tolerance [40], but more strikingly with height in humans, where the cumulative total effects of identified outliers (univariate approach) only explain 5% of variation, as opposed to a polygenic approach that explained 45% of the phenotypic variation [41]. This demonstrates the inherent difficulty in detecting quantitative genetic differences with traditional outlier approaches.

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Table 1. GO Enrichment for the 331 Random Forest SNPs that Differentiate Freshwater from Brackish/Saltwater American Eel

GO ID	Ref.	SNPs	p Value	Term
Entire Set of 331 SNPs with a p Value <0.01 and Containing at Least Two SNPs				
0060174	4	2	0.0004	limb bud formation
0004683	5	2	0.0006	calmodulin-dependent protein kinase activity
0015026	6	2	0.0009	coreceptor activity
0043114	8	2	0.0016	regulation of vascular permeability
0040036	9	2	0.0021	regulation of fibroblast growth factor receptor signaling pathway
0060541	74	4	0.0025	respiratory system development
0051701	37	3	0.0029	interaction with host
0052126	11	2	0.0031	movement in host environment
0033276	12	2	0.0038	transcription factor TFTC complex
0030532	13	2	0.0044	small nuclear ribonucleoprotein complex
0070851	45	3	0.0051	growth factor receptor binding
0019059	15	2	0.0059	initiation of viral infection
0005669	16	2	0.0067	transcription factor TFIID complex
0048738	51	3	0.0072	cardiac muscle tissue development
0048286	17	2	0.0075	lung alveolus development
0005104	17	2	0.0075	fibroblast growth factor receptor binding
0050839	18	2	0.0084	cell adhesion molecule binding
0043535	18	2	0.0084	regulation of blood vessel endothelial cell migration
0006094	18	2	0.0084	gluconeogenesis
0044403	55	3	0.0088	symbiosis, encompassing mutualism through parasitism
0048646	310	7	0.0098	anatomical structure formation involved in morphogenesis
Subset Representing the Freshwater Module of 137 SNPs with a p Value <0.005				
0010927	48	3	0.0006	cellular component assembly involved in morphogenesis
0033276	12	2	0.0008	transcription factor TFTC complex
0005669	16	2	0.0015	transcription factor TFIID complex
0006094	18	2	0.0018	gluconeogenesis
0019319	23	2	0.003	hexose biosynthetic process
0005509	286	5	0.0031	calcium ion binding
Subset Representing the Brackish/Saltwater Module of 45 SNPs with a p Value <0.005				
0050920	31	2	0.0005	regulation of chemotaxis
0050795	40	2	0.0009	regulation of behavior
0070851	45	2	0.0011	growth factor receptor binding
0003779	209	3	0.0014	actin binding
0005126	56	2	0.0017	cytokine receptor binding
0060541	74	2	0.003	respiratory system development
0048878	283	3	0.0033	chemical homeostasis
0008092	313	3	0.0043	cytoskeletal protein binding
0001666	90	2	0.0045	response to hypoxia
0019058	92	2	0.0046	viral infectious cycle
0070482	93	2	0.0047	response to oxygen levels

99 of these SNPs were within a gene. The columns represent the GO identifier enriched, the number of genes implicated for that term in the entire annotation for the genome (Ref.), the number of genes implicated in that term for the random forest SNPs most important in distinguishing the ecotypes (SNPs), and the name of the term. Terms from both the biological process and molecular function and only terms enriched with at least two SNPs were included.

Implications for Management and Beyond

There is great conservation concern for the freshwater ecotype of the American eel. The most extreme case is individuals in the Lake Ontario-Upper St. Lawrence River, where individuals are 99.9% female and can reach lengths exceeding 1 m and ages exceeding 20 years before maturing (Figure 1). Notably, these individuals also have the longest spawning migration requiring an abundance of energy reserves [5]. Namely, due to hydroelectric dams, overfishing, and pollution, abundance in the Lake Ontario-Upper St. Lawrence River, which is exclusively freshwater habitat, has declined by 99% in the past 40 years [42]. This is especially alarming because this area is nearly exclusively composed of large females and has historically represented a large percentage of fecundity for the entire species [26]. In contrast, Atlantic Canada includes a diversity of habitats (fresh, brackish, and saltwater), but commercial fishing primarily occurs in brackish and saltwater [43]. This ecotype sustains the fishery in that region and has been relatively stable over the same time period [43]. Given that the species is panmictic, managers have assumed that the divergent phenotypes were 100% the result of phenotypic plasticity in contrasted environments. Our results demonstrate the presence of a genetic component to the divergent ecotypes and help explain why transplanted young eels from abundant rearing areas fail to exhibit the freshwater ecotype [44].

These findings are most relevant for the management practices of *Anguilla* sp. Genetic diversity must be conserved in eel contingents associated with the different ecotypes. Mitigation efforts (fish ladders, transporting individuals that are naturally migrating safely around dams) should be maintained for the rarefying individuals of the Lake Ontario and Upper St. Lawrence River. Indeed, these individuals are homozygous, or nearly so, for the many alleles resulting in this most extreme example of the freshwater ecotype. However, the genetic diversity found in this depleted contingent is also present in other freshwater-rearing groups (correct allelic combinations for freshwater) and is even contained in the brackish/saltwater groups, albeit not in the correct allelic combinations for freshwater in this generation. Management should continue to support the robust numbers in many coastal populations in order to conserve genetic diversity in the panmictic species that is essential for the intra-generational mechanisms to continue. Our results thus bring strong support to the hypothesis that ecotypic differences between eels occupying different habitats is not the sole effect of plasticity but may also be caused by functional genetic differences stemming from intra-generational spatially varying selection and/or genotype-dependent habitat choice (or both) of ecologically divergent habitats.

Furthermore, despite a lack of genetic subdivision, these mechanisms would occur within each generation to result in divergent ecotypes associated with distinct habitat use. Thus, the commonly held assumption that plasticity is the only reason for phenotypic differences in systems with weak population subdivision (such as marine species with planktonic dispersal) must be re-evaluated. Similar patterns have been found in recent studies of divergence that have sufficient resolution or design to detect such subtle genomic changes [39, 45, 46].

ACCESSION NUMBERS

The contigs containing the 331 random forest SNPs and raw genotypes for all samples are archived in the Dryad repository at http://dx.doi.org/10.5061/dryad.n1mn9.

SUPPLEMENTAL INFORMATION

Supplemental Information includes Supplemental Discussion, Supplemental Experimental Procedures, two figures, and two tables and can be found with this article online at http://dx.doi.org/10.1016/j.cub.2015.04.062.

AUTHOR CONTRIBUTIONS

S.A.P. analyzed the data and wrote the paper. J.G. performed the lab work, analyzed the data, and wrote the methods. E.N. analyzed the data. M.D., C.A., M.C., and L.B. conceived and planned the study. L.B. co-wrote the paper, and all authors contributed substantially to revisions.

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The Genetic Consequences of Spatially Varying Selection in the Panmictic American Eel (*Anguilla rostrata*)

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ABSTRACT Our understanding of the genetic basis of local adaptation has recently benefited from the increased power to identify functional variants associated with environmental variables at the genome scale. However, it often remains challenging to determine whether locally adaptive alleles are actively maintained at intermediate frequencies by spatially varying selection. Here, we evaluate the extent to which this particular type of balancing selection explains the retention of adaptive genetic variation in the extreme situation of perfect panmixia, using the American eel (*Anguilla rostrata*) as a model. We first conducted a genome scan between two samples from opposite ends of a latitudinal environmental gradient using 454 sequencing of individually tagged cDNA libraries. Candidate SNPs were then genotyped in 992 individuals from 16 sampling sites at different life stages of the same cohort (including larvae from the Sargasso Sea, glass eels, and 1-year-old individuals) as well as in glass eels of the following cohort. Evidence for spatially varying selection was found at 13 loci showing correlations between allele frequencies and environmental variables across the entire species range. Simulations under a multiple-niche Levene's model using estimated relative fitness values among genotypes rarely predicted a stable polymorphic equilibrium at these loci. Our results suggest that some genetic-by-environment interactions detected in our study arise during the progress toward fixation of a globally advantageous allele with spatially variable effects on fitness.

VARIABLE environmental conditions across species' ranges provide a basis for differential selection at polymorphic loci involved in local adaptation. In consequence, the level of locally adaptive genetic variation may be potentially increased, through a particular type of balancing selection whereby protected polymorphisms result from selection for different alleles in different environments. Depending on population structure, the degree of habitat choice, and the strength of selection, this process can lead to habitat specialization and eventually to ecological speciation (Maynard Smith 1966). However, when both dispersal across habitats and mating are random processes, local adaptation is impossible and polymorphism may be either lost by drift or, under special conditions, protected by selection (Yeaman and Otto 2011). This evolutionary mechanism was first investigated more than half a century ago (Levene 1953), through a local density regulation model integrating variation in fitness of genotypes across niches and differential contribution of the niches to a panmictic reproductive pool. Levene demonstrated that a sufficient condition for a locally adaptive polymorphism to be maintained by selection requires the harmonic mean fitness of the heterozygote genotype to be higher than that of each homozygote, a process called "harmonic mean overdominance".

There is an increasing body of empirical evidence for cases of polymorphisms maintained by environmental heterogeneity (reviewed by Hedrick *et al.* 1976; Hedrick 1986, 2006).The most famous examples come from studies of allozyme variation (*e.g.*, Kreitman 1983; Sezgin *et al.* 2004), color polymorphism (Nachman *et al.* 2003; Hoekstra *et al.* 2004), adaptation to climate (Hancock *et al.* 2008; Kolaczkowski *et al.* 2011), and soil type (Turner *et al.* 2010), as well as pathogen and insecticide resistance (Garrigan and Hedrick

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2003; Weill *et al.* 2003; Pelz *et al.* 2005). Since habitat choice or reduced gene flow increases the opportunity for the maintenance of locally adaptive polymorphisms in subdivided populations (Felsenstein 1976), these cases are usually more fully understood under migration–selection models. However, the framework of Levene's model remains highly relevant to the study of species for which random mating and dispersal exist over large (*e.g.*, marine fishes and invertebrates) or local spatial scales (*e.g.*, sympatric host races of insects).

To date, the principal limitation to evaluating the retention of locally adaptive alleles in such species has been the lack of genomic resources. Only two studies that focused on one or two selected genes have empirically tested the maintenance of polymorphism under Levene's model, in the leafhopper (Prout and Savolainen 1996) and the acorn barnacle (Schmidt and Rand 2001). In practice, the discovery of locally adaptive polymorphisms in panmixia is not straightforward for several reasons. First, there might be a negative trade-off between the number of loci influenced by spatially varying selection and individual locus effects on fitness, such that the whole adaptive load due to selection on unlinked loci remains sustainable for the population. Second, environmental changes can shift the frequency of some protected variants out of their domain of stability, resulting in the loss of formerly stable polymorphisms. Third, recombination should rapidly erase the effects of selection on the chromosomal neighborhood of the selected sites (Charlesworth *et al.* 1997; Przeworski 2002). As such, partial selective sweeps provoked by the establishment of new protected variants should leave only transient genomic footprints, further reducing the chance to find them. Nevertheless, these difficulties can be partly overcome by tracking protected polymorphisms using a high-density genome-scan approach. Owing to the development of high-throughput sequencing techniques, this strategy is now achievable in most nonmodel species (Stapley *et al.* 2010).

The American eel *Anguilla rostrata* is one of the most appropriate organisms for studying the evolutionary effects of spatially varying selection within Levene's model framework (Karlin 1977). Mating of the whole species occurs in the Sargasso Sea (Schmidt 1923), after which planktonic larvae are dispersed by the Antilles Current and the Gulf Stream to the eastern North American coast over a large continental habitat, extending from Florida to Quebec and Labrador (Tesch 2003). Studies based on neutral molecular markers have shown that in this textbook example of panmixia, random mating occurs at the species scale (Avise *et al.* 1986; Wirth and Bernatchez 2003). Evidence from the literature also supports that leptocephali larvae passively drift with the currents (Bonhommeau *et al.* 2010) and that, following metamorphosis, newly transformed unpigmented glass eels use a selective tidal stream transport mechanism to move landward (McCleave and Kleckner 1982). Thus, genotype-dependent habitat choice is unlikely to occur over a large geographical scale due to oriented horizontal swimming and newly recruited glass eels are exposed to highly unpredictable conditions with respect to environmental parameters (*e.g.*, temperature, salinity, pathogens, and pollutants) during their early life history. Consistent with these observations, clinal variation attributed to single-generation footprints of spatially varying selection was found at three allozyme loci (Williams *et al.* 1973; Koehn and Williams 1978). However, allozyme studies focused on only a few metabolic genes and did not assess the retention of locally adaptive polymorphisms by spatially varying selection. Population genomics now offers powerful tools to bring empirical data to bear on this fundamental question in ecological genetics. Here, we discovered and typed annotated single-nucleotide polymorphisms (SNPs) in transcribed regions of the American eel genome to identify candidate genes potentially associated with environmental variables. An extensive spatiotemporal set of samples was then used to further test for selection at candidate loci, estimate niche-specific relative fitness among genotypes, and investigate conditions for the maintenance of polymorphism under a finite-population Levene's model.

Materials and Methods

Preparation of cDNA libraries, contig assembly, and SNP discovery

We prepared cDNA libraries for 454 sequencing following the protocol described in Pierron *et al.* (2011). Two samples of 20 glass eels were collected just prior to settlement in freshwater at two river mouths located near the extreme ends of the species' latitudinal range: the Grande Rivière Blanche in the lower St. Lawrence estuary (RB, 48°78′N, 67°70′W) and Florida (FL, 30°00′N, 81°19′W). Briefly, Poly(A) RNAs were individually extracted from entire glass eels and used as a template for cDNA amplification. Amplified cDNAs were then fragmented by sonication, and fragments from 300 to 800 bp were ligated to the standard 454 B primer and the standard 454 A primer, holding a 10-bp barcode extension at its 3′ end. Therefore, each individual could be identified by its unique barcode. For each sampling site, the 20 individually tagged libraries were pooled in equal amounts and sequenced on a half-plate of Roche GS-FLX DNA Sequencer at Genome Quebec Innovation Center (McGill University, Montreal, QC, Canada).

Base calling was performed using PyroBayes (Quinlan *et al.* 2008) after trimming adapters. Each read was then renamed according to its individual barcode, which was subsequently removed together with potential primers used for cDNA amplification. We performed a *de novo* assembly of the total sequencing data using CLC Genomic Workbench 3.7 (CLC bio), with a minimal read length fraction of 0.5 and a similarity parameter of 0.95. The consensus sequence of each *de novo* built contig was then used as a template for a reference assembly under the same parameters. This second round of assembly aimed at screening for additional reads that were not included into contigs during the step of *de novo* assembly and excluding poor-quality contigs that did not recruit any read during the reference assembly procedure.

SNP discovery was performed using the neighborhood quality standard (NQS) algorithm (Altshuler *et al.* 2000; Brockman *et al.* 2008) implemented in CLC Genomic Workbench 3.7 (CLC bio). This method takes into account the base quality values to distinguish sequencing errors from actual SNPs. We set a minimum coverage of 20× per SNP site and used either a frequency threshold of 5% or a count threshold of 5 for the rarest variant (when the coverage exceeded 100×) to avoid the detection of sequencing errors as SNPs. Only biallelic SNPs were considered.

Individual genotype inference

There is a significant risk to misscore a heterozygote genotype by repeatedly sampling the same allele when the individual coverage is <5× (see Supporting Information, Figure S1). We corrected such artifactual heterozygote deficiencies by supposing within-sample Hardy–Weinberg equilibrium (HWE) while taking into account the stochasticity induced by the binomial sampling process of homologous sequences at each locus for each individual. For each SNP having >10 individuals sequenced in each sample (*i.e.*, total coverage ≥20×), allele counts were used to determine the observed genotype of each individual (*AA*, *Aa*, *aa*, or NA when no sequence data were available) to calculate the observed allelic frequencies. We then supposed within-sample HWE to estimate the number of expected individuals within each genotypic class in each sample given the number of individuals sequenced and the observed allelic frequencies in the sample. When the observed number of heterozygotes was below HWE predictions, new genotypes that were consistent with observed individual data were randomly drawn from a trinomial distribution with event probabilities $(P(AA)_{i,j}; P(Aa)_{i,j}; P(aa)_{i,j})$ corresponding to the probabilities of each genotype, given the observed data for the *j*th individual in sample *i*. For each locus showing HW deficiency, a new array of individual genotypes was generated until HWE expectations were verified for the sample. The individual genotype probabilities used to parameterize the trinomial sampling process were obtained from the following equation giving the probabilities of real genotypes (G_{R}) knowing the observed data (G_{O}) at a given locus,

$$
\begin{aligned}
&P(G_{\mathrm{R}}|G_{\mathrm{O}})_{i,j}\\
&\quad=\left(P(AA)_{i,j};\ P(Aa)_{i,j};\ P(aa)_{i,j}\right)\\
&\quad=\begin{pmatrix}
\dfrac{p_i^2}{p_i^2+p_i(1-p_i)(1/2)^{(N_{i,j}-1)}} & 0 & 0\\
\dfrac{p_i(1-p_i)(1/2)^{(N_{i,j}-1)}}{p_i^2+p_i(1-p_i)(1/2)^{(N_{i,j}-1)}} & 1 & \dfrac{p_i(1-p_i)(1/2)^{(N_{i,j}-1)}}{(1-p_i)^2+p_i(1-p_i)(1/2)^{(N_{i,j}-1)}}\\
0 & 0 & \dfrac{(1-p_i)^2}{p_i^2+p_i(1-p_i)(1/2)^{(N_{i,j}-1)}}
\end{pmatrix}\\
&\qquad\times\ G_{\mathrm{o}_{i,j}},
\end{aligned}
$$

where $N_{i,j}$ is the number of reads (*i.e.*, individual coverage) of individual *j* in sample *i*, $G_{\mathrm{o}_{i,j}}$ is its observed genotype

$$
\left(\text{with } G_O(AA)=\begin{pmatrix}1\\0\\0\end{pmatrix},\ G_O(Aa)=\begin{pmatrix}0\\1\\0\end{pmatrix},\ \text{and } G_O(aa)=\begin{pmatrix}0\\0\\1\end{pmatrix}\right),
$$

and p_i is the frequency of the *A* allele in sample *i*. Under this procedure, the genotype of an observed heterozygote was never modified, whereas observed homozygotes could be probabilistically assigned to heterozygotes. Since the sequencing error rate was already taken into account by the SNP detection method, it was neglected at this step to simplify the approach. Methodological validation performed on simulated data sets showed that our correction efficiently restored up to 50% of the hidden heterozygotes (see Figure S1).

Outlier detection

Individual genotypes obtained after treating for the heterozygote deficiency bias were used to detect SNPs potentially affected by diversifying selection between the two samples RB and FL. The empirical distribution of pairwise F_{ST} as a function of within-samples heterozygosity was compared to a neutral distribution simulated under a symmetrical two-island model assuming near random mating (Beaumont and Nichols 1996), using ARLEQUIN ver. 3.5 (Excoffier and Lisher 2010). This approach is more conservative than drawing random samples from a single panmictic population to derive the neutral distribution. For each outlier locus (*i.e.*, F_{ST} value located above the 99.5% quantile of the simulated distribution), the contig's consensus sequence was blasted against the nonredundant NCBI protein database (*nr*), using BLASTX with an *E*-value threshold of 10^{-5} (Altschul *et al.* 1997).

SNP genotyping

Individual SNP assays were developed using the KBiosciences Competitive Allele-Specific PCR genotyping system (KASPar). For each candidate contig, we targeted the SNP showing the highest F_{ST} value when possible. We also developed assays for SNPs identified within contigs of allozyme coding genes showing clinal variation in Williams *et al.* (1973): the *Sorbitol dehydrogenase* gene (*SDH*), two *Phosphoglucose isomerase* isoforms (*PGI-1* and *PGI-2*), and the *Alcohol dehydrogenase* gene (*ADH-3*). Our validation panel was finally completed with nonoutlier SNPs to 100 markers. All assays were tested with 80 individuals and only successfully genotyped SNPs were retained for subsequent genotyping.

A total of 992 individuals belonging to four distinct sample categories were genotyped (Table 1): (i) A reference sample of the 2007 cohort (before selection) consisting of 48 young leptocephali larvae collected in the Sargasso Sea soon after hatching in March and April 2007 (*SAR7*) during the Galathea III expedition (Munk *et al.* 2010); (ii) the first wave of recruiting glass eels belonging to the 2007 cohort, collected between January and July 2008 at 16 river mouths distributed from Florida to Quebec (*GLASS8*); (iii) 1-year-old individuals from the 2007 cohort, sampled between February and June 2009 from four localities previously sampled in 2008, ranging between South Carolina and Quebec (*OYO9*); and (iv) glass eels belonging to the 2008 cohort, collected in 2009 at 5 river mouths distributed from South Carolina to Quebec (*GLASS9*) and that were also sampled in 2008 for the 2007 cohort.

Statistical analyses

We tested for HWE at each diploid locus within each of the four eel sample categories, using ARLEQUIN ver. 3.5 (Excoffier and Lisher 2010). We corrected for multiple independent tests using the false discovery rate correction ($\alpha = 0.05$). Multilocus global F_{ST} values among localities within sample categories were estimated and tested through 10,000 permutations. Outlier SNPs were searched on the basis of their level of genetic differentiation among localities within categories as well as between pairs of localities, using coalescent simulations under a symmetrical island model assuming near random mating.

For each locus, statistical associations between allelic frequencies and a set of four explanatory variables (sample category, latitude, longitude, and temperature) were assessed through logistic regressions using the R package *glmulti* (Calcagno and De Mazancourt 2010). Temperature data were obtained from a National Oceanic and Atmospheric Administration (NOAA) database containing georeferenced sea-surface temperatures along North America's coastlines (SST14NA), with a nominal spatial resolution of 14 km and a 48-hr update frequency. More precisely, we took the sea-surface temperature at river mouth averaged across the 10 days preceding the sampling date in each locality, which corresponded to recruitment at river mouths for the *GLASS8* category. Because the exact date of arrival at river mouths was not known for the two other categories of samples, we used different temperature criteria: the three winter months (December to February) average river mouth temperature was used for the *OYO9* category, and the sampling month average river mouth temperature was used for the *GLASS9* category (Table 1). All possible models involving the four explanatory variables (including pairwise interactions) were fitted using samples from the three continental categories (*GLASS8*, *OYO9*, and *GLASS9*), and the best model was identified using a Bayesian information criterion (BIC). Because the best geographical coverage was achieved for the 2008 glass eels, the same approach was also performed using samples from the *GLASS8* category only. For each SNP found in association with explanatory variables, individual haplotype information was retrieved from 454 sequencing data and used to evaluate between-sites linkage disequilibrium (LD), using the method for partially phased haplotypes in Haploview v4.2 (Barrett *et al.* 2005).

The multilocus spatial component of genetic variability at loci inferred to be influenced by spatially varying selection was determined using the spatial principal component analysis method (sPCA) (Jombart *et al.* 2008) implemented in the R package *adegenet_1.2-2* (Jombart 2008). The sPCA includes spatial information in the analysis of genetic data, which helps to reveal subtle global spatial structures such as geographic clines. The spatial proximity network among localities was built using the neighborhood-by-distance method. An abrupt decrease of the eigenvalues obtained by decomposing the genetic diversity from the spatial autocorrelation was used as a criterion to choose the principal component to interpret.

Evolution under Levene's model

The classical one-locus–two-allele model of Levene (1953) was extended by the addition of a genetic drift component. At each generation, mating occurs in panmixia, followed by random dispersal of genotypes across niches. Selection is a niche-specific process in which the frequency of allele A before selection in the ith niche, noted q_i, passes to q_i' after selection following the equation

$$q_i' = \frac{W_i q_i^2 + q_i(1-q_i)}{W_i q_i^2 + 2q_i(1-q_i) + V_i(1-q_i)^2},$$

where W_i and V_i, respectively, denote the fitness of the homozygote genotypes AA and aa relative to that of the heterozygote genotype in the ith niche. Genetic drift is then modeled by randomly drawing $N_{\mathrm{e}} \times C_i$ genotypes in each niche from a trinomial distribution with event probabilities

$$\left(P(AA)_i = q_i'^{\,2};\ P(Aa)_i = 2q_i'\left(1-q_i'\right);\ P(aa)_i = \left(1-q_i'\right)^2\right).$$

The new frequency of allele A after selection and drift in the ith niche is noted q_i'' and since C_i corresponds to the relative contribution of niche i to the global reproductive pool of effective size N_{e}, the frequency of allele A equals $\sum_i C_i q_i''$ in the next mating pool.

To test for equilibrium under Levene's model, empirical values of W_i and V_i were estimated from the observed genotypic frequencies in the *SAR7* larval pool ($f_{AA}; f_{Aa}; f_{aa}$) and the modeled niche-specific genotypic frequencies after selection ($f_{AA'_i}; f_{Aa'_i}; f_{aa'_i}$) following

$$W_i = \frac{f_{AA'_i} f_{Aa}}{f_{AA} f_{Aa'_i}} \quad \text{and} \quad V_i = \frac{f_{aa'_i} f_{Aa}}{f_{aa} f_{Aa'_i}},$$

where the ratios $f_{AA'_i}/f_{Aa'_i}$ and $f_{aa'_i}/f_{Aa'_i}$ were predicted by the regression models of $f_{AA'}/(f_{AA'} + f_{Aa'})$ and $f_{aa'_i}/(f_{aa'_i} + f_{Aa'})$, using the observed genotypic frequencies in the *GLASS8* samples and the explanatory variables previously selected for this category (see *Results*). For each locus inferred to be influenced by spatially varying selection, the 16 estimated pairs of (W_i; V_i) were used to parameterize a 16-niche Levene's model in which the allelic frequencies observed in *SAR7* were used as starting values. Different distributions of the C_i were explored, from uniform to normally distributed

Table 1 Sampling location and date, sample size, developmental stage, and river mouth temperature for each analyzed sample

Category	Sampling locality	Code	Development stage	*N*	Latitude	Longitude	Day	Month	Year	Temperature (°)
SAR7	Sargasso Sea	SAR_7	Leptocephali	48	—	—	—	—	2007	—
GLASS8	Gaspésie, Grande Rivière Blanche	GAS_G8	Glass eel	40	48.78	−67.70	14	June	2008	14.21[a]
	Newfoundland, Codroy Bay	NF_G8	Glass eel	40	47.85	−59.26	16	July	2008	15.86[a]
	Prince Edward Island, Rustico Bay	PEI_G8	Glass eel	40	46.43	−63.24	3	July	2008	19.83[a]
	New Scotia, St. John's River	NS_G8	Glass eel	40	45.54	−64.70	25	April	2008	3.41[a]
	Maine, Boothbay Harbor	MAI_G8	Glass eel	40	43.85	−69.65	1	May	2008	6.22[a]
	New Hampshire, Taylor River	NH_G8	Glass eel	40	42.91	−70.84	23	April	2008	6.78[a]
	Massachusetts, Parker River	MA_G8	Glass eel	40	42.69	−70.79	16	April	2008	7.04[a]
	Connecticut, Taylor River	CO_G8	Glass eel	40	41.41	−70.55	5	May	2008	10.44[a]
	New Jersey, Patcong Creek	NJ_G8	Glass eel	40	41.17	−72.23	4	April	2008	7.79[a]
	Pensylvania, Delaware River	PEN_G8	Glass eel	40	39.89	−75.26	1 to 5	May	2008	9.50[a]
	Delaware, Millsboro Pond Spillway	DEL_G8	Glass eel	40	38.35	−75.17	5	February	2008	7.00[a]
	Virginia, Wormley Creek	VIR_G8	Glass eel	40	37.21	−76.49	28	March	2008	10.01[a]
	North Carolina, Black Creek	NC_G8	Glass eel	40	34.46	−76.48	5 to 7	February	2008	10.44[a]
	South Carolina, Cooper River	SC_G8	Glass eel	40	32.55	−80.00	13	February	2008	17.19[a]
	Georgia, Altamaha River	GEO_G8	Glass eel	22	31.18	−81.28	8 to 23	January	2008	15.46[a]
	Florida, Guana River	FLO_G8	Glass eel	40	30.00	−81.19	28	January	2008	18.09[a]
OYO9	Gaspésie, Grande Rivière Blanche	GAS_E9	Elver 1+	35	48.79	−67.70	—	June	2009	0.16[b]
	Massachusetts, Parker River	MA_E9	Elver 1+	39	42.69	−70.79	—	April	2009	5.62[b]
	Pensylvania, Crum Creek	PEN_E9	Elver 1+	40	39.86	−75.32	—	May	2009	7.22[b]
	South Carolina, Cooper River	SC_E9	Elver 1+	29	32.55	−80.00	—	February	2009	14.68[b]
GLASS9	Gaspésie, Grande Rivière Blanche	GAS_G9	Glass eel	40	48.79	−67.70	—	June	2009	10.57[c]
	Nova Scotia, Caledonia	NS_G9	Glass eel	40	46.04	−59.96	—	June	2009	9.55[c]
	Massachusetts, Parker River	MA_G9	Glass eel	39	42.69	−70.79	—	April	2009	5.65[c]
	Pennsylvania, Crum Creek	PEN_G9	Glass eel	40	39.86	−75.32	—	May	2009	13.57[c]
	South Carolina, Cooper River	SC_G9	Glass eel	20	32.55	−80.00	—	February	2009	12.31[c]

[a] Ten-day average sea-surface temperature before sampling date (source NOAA: SST14NA).
[b] Three winter months (December through February) average sea-surface temperature (source NOAA: SST14NA).
[c] Sampling month average sea-surface temperature (source NOAA: SST14NA).

outputs among niches, and the population effective size parameter was set between 10^4 and 10^6 to assess genetic drift effects.

Results

Sequence assembly and SNP discovery

A total of 292.6 Mb of sequences were obtained from the two half-runs of 454 GS-FLX pyrosequencing, among which were 482,322 reads from the St. Lawrence estuary sample (RB, mean read length of 296 bp) and 495,482 reads from the Florida sample (FL, mean read length of 303 bp). These sequences were deposited in the NCBI sequence read archive SRA045712. Trimming adapters and individual barcodes and then filtering for sequence quality removed 5.3% of the reads from the RB data set and 5.1% from the FL data set. Processed reads were assembled into 22,093 contigs with an average length of 464 bp. *In silico* SNP detection allowed identifying 70,912 putative SNPs, 13,293 of which were retained after filtering for a minimal coverage of 10 reads from at least 10 different individuals in both samples RB and FL (*i.e.*, total coverage ≥20×). This filtering step allowed inferring 78.1% of the 265,860 genotypes (20 individuals × 13,293 SNPs) in sample RB and 79.7% in sample FL.

Candidate SNP detection and genotyping

A total of 163 outlier SNPs with estimated F_{ST} values ranging from 0.167 to 0.637 were detected (see Figure S2). However, for most candidate SNPs exhibiting the highest F_{ST} values, BLAST searches revealed the presence of reads matching alternative copies of duplicated genes within contigs. These false SNPs, which probably reflected differential expression patterns of paralogous genes (principally myosin isoforms) between samples RB and FL, were removed from subsequent analyses.

After these filtering procedures, our validation panel included 57 outlier SNPs and was completed to 100 markers with nonoutlier SNPs selected across the full range of heterozygosity. Successful genotyping was obtained for 73 of these 100 SNPs (see File S1), 70 of which were functionally annotated using BLASTX (see Table S1), and 44 were outliers from the initial screen. The genotyping success rate across all samples and loci was >98%; KASPar primers used for genotyping are provided Table S2.

Table 2 Models selected for 13 loci associated with explanatory variables, for both the *GLASS8* data set and the three continental categories

Locus	Gene	*GLASS8*	Slope *P*-value	Three continental categories	Slope *P*-value
ACP_13914	*Acyl carrier protein*	TEMP	0.0013	TEMP	0.0001
ANX_2_249	*Annexin A2-A*	TEMP:LAT	0.0385	TEMP+TEMP:LONG+TEMP:LAT+LAT:LONG	0.0017[a]
CST_21113	*Cystatin*	Null	—	TEMP:COHORT	0.0021
EIF_3F_341	*Translation initiation factor 3 subunit F*	Null	—	TEMP	0.0075
GPX_4_19607	*Glutathione peroxidase 4*	TEMP:LONG	0.0013	TEMP:LONG	0.0008
HSP_90A_15666	*Heat-shock protein 90 alpha*	TEMP:LONG	0.0355	TEMP+LONG+TEMP:LONG	0.0058[a]
MDH_1393	*Malate dehydrogenase*	TEMP:LONG	0.0403	Null	0.0874[b]
NCP_2_15547	*Nucleolar complex protein 2*	Null	—	TEMP	0.0539
NRAP_1541	*Nebulin-related anchoring protein*	TEMP:LAT	0.0425	TEMP:LONG	0.0590
PRP_40_16504	*Pre-mRNA–processing factor 40 homolog A*	LAT	0.0044	TEMP+LAT+TEMP:LAT	0.0202[a]
SN4_TDR_374	*Staphylococcal muclease domain-containing protein 1*	Null	—	TEMP:LONG	0.0281
TENT_02_11046	—	Null	—	TEMP	0.0082
UGP_2_2128	*UDP-glucose pyrophosphorylase 2*	TEMP:LONG	0.0177	TEMP+COHORT+TEMP:COHORT	0.0318[c]

LAT, latitude; LONG, longitude; TEMP, temperature.

[a] *P*-value associated to the term identified as best model for *GLASS8*, in the best model for all three continental categories.

[b] *P*-value associated to the best model for *GLASS8*.

[c] *P*-value associated to the term TEMP, in the best model for all 3 continental categories.

SNP variation patterns

Only one locus departed significantly from HWE expectations within the *SAR7* category, whereas 15, 7, and 10 loci showed significant HW disequilibrium within the continental categories *GLASS8*, *OYO9*, and *GLASS9*, respectively (see Table S3). Overall multilocus F_{ST} values calculated among locality samples were not significantly different from zero within each of the three continental categories (*GLASS8*, $F_{ST} = 0.0003$, $P = 0.318$; *OYO9*, $F_{ST} = 0.0015$, $P = 0.171$; *GLASS9*, $F_{ST} = 0.0022$, $P = 0.060$).

Logistic regressions between allelic frequencies and explanatory variables based on the data set containing the three continental categories (*GLASS8*, *OYO9*, and *GLASS9*) revealed contrasting patterns across loci. For 61 of 73 SNPs, all possible models involving the explanatory variables and their pairwise interactions were rejected. However, significant associations were detected for 10 loci and marginally significant associations for 2 loci (Table 2). The same approach performed within the *GLASS8* category alone revealed statistical associations for 8 loci, all but *MDH* being already detected in the analysis including all continental samples (Table 2). Among the 13 loci for which significant associations were found, 11 were also detected in outlier tests due to atypically high F_{ST} values ranging from 0.052 to 0.175 between some pairs of localities. After removing these 13 loci from the data set, the global multilocus F_{ST} values calculated among locality samples became null in two continental categories (*GLASS8*, $F_{ST} = -0.0015$, $P = 0.981$; *OYO9*, $F_{ST} = -0.0007$, $P = 0.647$) and was reduced in the third one (*GLASS9*, $F_{ST} = 0.0016$, $P = 0.151$).

Most selected regression models revealed significant interactions between spatial variables and river mouth temperature (Table 2), which was measured at different timescales for the three continental categories (Table 1). River mouth temperature at recruitment was selected as the best model for one locus in the *GLASS8* category (*Acyl-Carrier Protein*, *ACP*; Figure 1A). To identify more precisely when this parameter was the most biologically relevant for this locus, we used a sliding-window analysis to test whether the correlation could be improved, using temperature data from different time periods surrounding glass eels recruitment. We found that the correlation was rapidly lost when the 10-days window used to calculate the average sea-surface temperature was shifted around the period corresponding to recruitment (Figure 1B). Furthermore, because the timing of glass eels' recruitment varied considerably across sampling locations, river mouth temperatures were neither correlated with latitude ($R^2 = 0.113$, $P = 0.203$) nor correlated with longitude ($R^2 = 0.036$, $P = 0.484$) during the recruitment period (Table 1).

Multivariate analysis of the eight loci significantly associated with explanatory variables in the *GLASS8* category showed that most of the variability was explained by the first principal component, since the first eigenvalue of the sPCA was highly positive (Figure 2, top right). The global structure illustrated by individual lagged scores on the first principal component showed a synthetic latitudinal cline (Figure 2), corresponding to the multilocus spatial component of genetic variation at the eight loci inferred to be under spatially varying selection. A logistic regression of locality scores against latitude ($R^2 = 0.76$, $P < 0.0001$) showed that the center of the cline coincides with the coastal zone where the latitudinal gradient of nearshore sea-surface temperature is the strongest over the sampling period. Moreover, river mouth temperature averaged across the whole sampling period was a better predictor of

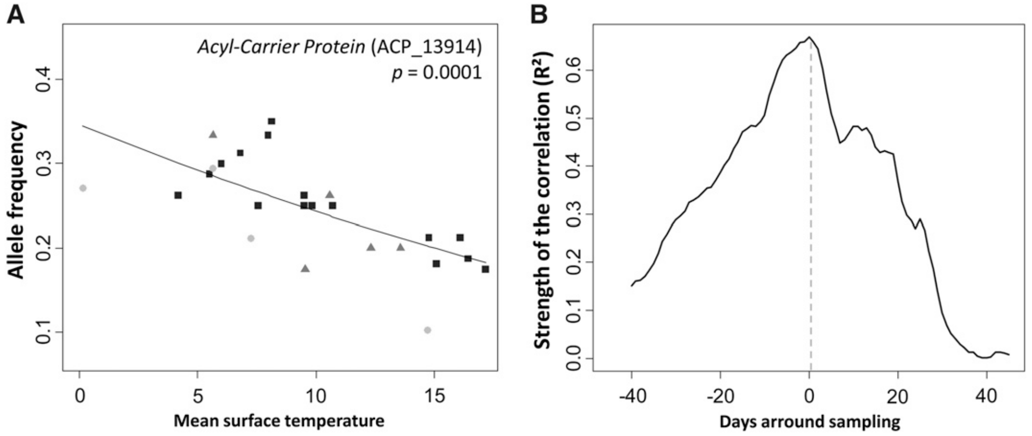

Figure 1 Correlation between river mouth temperature and allele frequencies at locus *ACP*. Logistic regression is based on all three continental categories. (A) Allele frequencies in the *GLASS8* category are represented by solid squares, *OYO9* by circles with light shading, and *GLASS9* by triangles with dark shading. (B) Sliding-window analysis of the coefficient of determination (R^2) between allele frequencies at locus *ACP* in the *GLASS8* category and the values predicted using river mouth temperature data. For each day within a 3-month period centered on the sampling date (which also corresponded approximately to the date of arrival at river mouths), surface temperature was taken as the mean value across the 10 previous days.

locality scores than latitude ($R^2 = 0.88$, $P < 0.0001$). A highly similar synthetic latitudinal cline was obtained when analyzing the three continental categories together (see Figure S3), supporting the temporal stability of the observed pattern.

One of the 13 SNPs associated with explanatory variables was a nonsynonymous polymorphism (*Nucleolar Complex Protein 2*, *NCP-2*), whereas for 9 of the 12 other SNPs, at least one nonsynonymous segregating site was identified within a 1-kb region (see Figure S4). Heterozygosity within the 13 contigs usually followed a monotonical trend and substantial levels of linkage disequilibrium ($r^2 > 0.5$) were sometimes found between remote SNPs. These results suggest that the indirect influence of selection through linkage with a nearby functional mutation was more likely than direct selection at the focal SNPs. However, this should not introduce any bias in the estimation of the relative fitness values used in the following simulations.

Assessment of polymorphism stability under Levene's model

Simulating the evolution of allelic frequencies for the eight loci significantly associated with explanatory variables in the *GLASS8* category led to two different predictions. Under the hypothesis of uniform contribution among niches and an effective population size (N_e) of 10^5, simulations predicted polymorphism stability for two SNPs and allele fixation for the remaining six loci (Table 3). The simulated evolution of allelic frequencies over generations as generated by the model can be found for each of the eight loci in Figure S5. Frequency at equilibrium was fairly close to that measured in the *SAR7* sample for the two SNPs predicted to be protected by spatially varying selection. Concerning the six transient polymorphisms, allele fixation was generally reached within <80 generations. Most importantly, the invading allele was always the derived state after identifying the ancestral allele through BLASTN search.

The results obtained under different assumptions on the relative contributions among niches and population size did not radically change these predictions, as the same two protected polymorphisms were repeatedly inferred across scenarios. However, estimating the niche-specific relative fitness directly from the observed genotype frequencies in the *GLASS8* category (*i.e.*, instead of using values predicted by the regression models) increased the number of protected polymorphisms from two to four (see Table S4).

Discussion

Evidence for single-generation footprints of spatially varying selection

Our results provide strong indications that young glass eels colonizing different areas of the species range are exposed to differential patterns of selection, resulting in significant shifts in allele frequencies within a short timescale. The alternative hypothesis of a subtle neutral population genetic structure in the American eel was not supported by previous works, since panmixia has never been rejected using neutral markers (Avise *et al.* 1986; Wirth and Bernatchez 2003). This conclusion was reiterated here on the basis of 60 neutral SNPs genotyped over 944 individuals distributed across three temporal categories. Moreover, a neutral pattern imposed by spatially restricted gene flow is not consistent with the finding that 85% (11 of 13) of the loci associated with explanatory variables were also detected as outliers and that different regression models were selected across these markers. Consequently, our data do not support the existence of a spatial population structure due to deviation from panmixia in *A. rostrata*. Alternatively, passive genotype-specific habitat choice could possibly occur if the genes associated with environmental variables underlie differences in leptocephalus stage duration. However, the observation that early-metamorphosing leptocephali preferentially recruit to the center of the continental distribution range, whereas late-metamorphosing larvae mostly settle in northern and southern locations (Wang and Tzeng 1998), is inconsistent with the clinal multilocus spatial component detected at

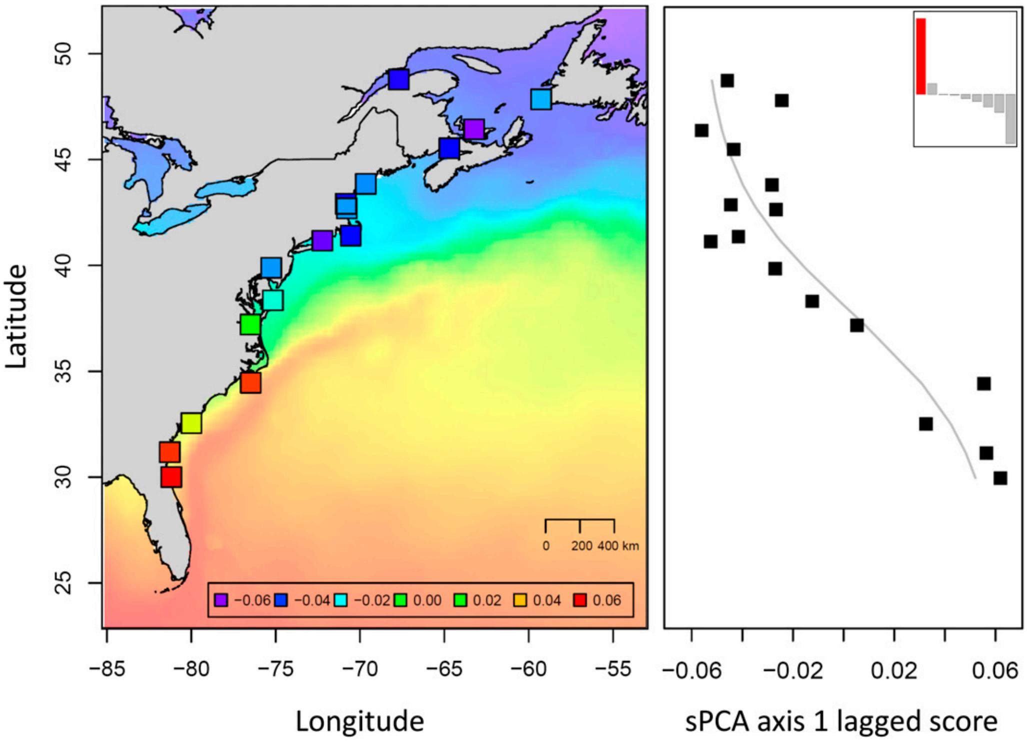

Figure 2 Synthetic multilocus spatial variation component in the 2008 glass eels. The spatial component analysis was based on genetic variation at the eight loci significantly associated with explanatory variables in the *GLASS8* category. The 16 sampling sites are represented on the map by squares colored according to each locality's lagged score on the first principal component, as indicated in the inset. Sea-surface temperatures averaged across the whole sampling period (from January 8 to July 16, 2008) are represented on the same color scale for indication (purple, 0.2°; red, 27.3°). The plot on the right shows the shape of the synthetic multilocus cline, as well as the decomposition of the product of the variance and the spatial autocorrelation into positive, null, and negative components (top right corner). The clinal structure corresponds to the highly positive eigenvalue in red.

these loci (Figure 2). Moreover, half of these loci displayed HWE deviations in continental samples but not in the larval sample, which is incompatible with the habitat choice hypothesis. Therefore, we propose that spatially varying selection is the most parsimonious mechanism underlying the observed patterns of genetic variation.

The diversity of the statistical models retained to explain genetic variation across selected loci may suggest the implication of different locus-specific selective factors. Without detailed information on such agents, the choice of spatial and temperature variables as proxies for the ecological conditions experienced by eels was justified, as, for instance, several environmental factors covary with latitude along the North Atlantic coasts (Schmidt *et al.* 2008). Covariation between latitude and spatially varying selective factors has previously been used to illustrate multilocus spatial patterns attributed to selection in heterogeneous environments in *Drosophila melanogaster* (Sezgin *et al.* 2004). Here, we additionally used this synthetic multilocus signal to demonstrate the overall temporal stability of the observed patterns (Figure S3). Owing to the apparent panmixia and the lack of evidence for large-scale habitat choice in the American eel, any genetic pattern left by spatially varying selection at a given generation will be inevitably erased at the next generation. Consequently, the temporal stability of the observed genetic patterns between the *GLASS8* and *GLASS9* categories probably reflects the repeated action of similar natural selection pressures in the two consecutive year cohorts covered by this study. Given that only a very small proportion ($<$0.5%) of the larvae survive until glass eels reach the coasts and that the glass eel survival rate is $\sim$10% (Bonhommeau *et al.* 2009), our sampling scheme was designed with the intent to detect changes in allelic frequencies occurring during the early stages of eels' life

Table 3 Simulated evolution of allelic frequencies under Levene's model for the eight loci statistically associated with explanatory variables in the *GLASS8* category

Locus	Predictive model	$1/\sum(C_i/W_i)$	$1/\sum(C_i/V_i)$	Frequency Sargasso	Levene's model prediction
ACP_13914	TEMP	0.7661	1.3688	0.6875	Fixation of the derived allele
ANX_2_249	TEMP:LAT	0.8325	0.2900	0.9565	Equilibrium at 0.81
GPX_4_19607	TEMP:LONG	1.0031	1.8379	0.9149	Fixation of the derived allele
HSP_90A_15666	TEMP:LONG	2.1926	1.0759	0.1170	Fixation of the derived allele
MDH_1393	TEMP:LONG	0.6397	0.7761	0.3913	Equilibrium at 0.375
NRAP_1541	TEMP:LAT	0.6065	1.1201	0.5426	Fixation of the derived allele
PRP_40_16504	LAT	4.7856	1.1736	0.1277	Fixation of the derived allele
UGP_2_2128	TEMP:LONG	0.7568	1.4254	0.4468	Fixation of the derived allele

Uniform contribution among niches and a population effective size of 10^5 were assumed in these simulations.

cycle. Moreover, we sampled the first wave of early-recruiting glass eels before potential settlement cues may affect up-estuary migration depending on individual condition and temperature (Sullivan *et al.* 2009).

Although we used variables that mirror continental factors better than open-ocean factors, a decoupling between river mouth and nearshore continental shelf sea-surface temperatures in the northeastern part of the species range [localities Gaspésie (GAS), Newfoundland (NF), and Prince Edward Island (PEI); Table 1] may have influenced our results. Glass eels recruiting in this region during early summer first face cold water temperatures while crossing the continental shelf before entering warmer estuary waters influenced by river outflows. Differential mortality during the cross-shelf transport may thus have resulted in the selection of explanatory models involving interactions between river mouth temperature and latitude or longitude, as observed for six loci of eight in the *GLASS8* category. This interpretation is further supported by the close correspondence between the multilocus spatial variation component and the nearshore averaged sea-surface temperature pattern in Figure 2. Although it suggests that the continental shelf sea-surface temperature should have been used in the regression analyses, this variable remains too difficult to measure without knowing the trajectories of eels during the cross-shelf transport. Using hydrodynamic models for back-tracking larval transport may thus help in selecting additional meaningful variables in future studies. Admittedly, as in any other study of this type, our approach cannot fully capture the signal of all spatially varying selection pressures and probably underestimates the number of genes under spatially varying selection. On the other hand, the strong association found at locus *Acyl-Carrier Protein* (*ACP*) between allele frequencies and temperature at recruitment (Figure 1) shows that the river mouth temperature is a relevant variable. Indeed, settlement in estuaries is a critical period during which glass eels do not feed (Sullivan *et al.* 2009) and probably live on their fatty acids reserves.

Three of the five allozymes previously studied (Williams *et al.* 1973) were included in our analysis to assess whether clines observed at the protein level could be detected at the DNA level. The SNP developed for the *Malate dehydrogenase* gene (*MDH*), which was also detected as an outlier in our initial 454 transcriptome scan, was the only one to show a significant association with environmental variables. In the allozyme study, however, genetic heterogeneity at this locus was observed only among samples of adults and not at the glass eel stage. The lack of a significant pattern for the SNPs developed at the *ADH* and *PGI* loci may be due to problems of paralogy or to a lack of LD with the SNPs under selection.

The fate of selected polymorphisms under Levene's model

Covariation between environmental variables such as temperature and the direction and strength of selection has been suspected for a long time to actively maintain polymorphisms in heterogeneous environments (reviewed by Hedrick *et al.* 1976; Karlin 1977). Depending on the overall sum of local selective effects, spatially varying selection can, however, lead to two different outcomes: (i) balanced selection for different alleles in different environments can maintain polymorphism over generations, while (ii) globally unbalanced local effects of directional selection may lead to allelic fixation (Levene 1953). Recent theoretical developments have shown that substantial multilocus polymorphism can be maintained under Levene's model, in particular when locally advantageous alleles are partially dominant (Bürger 2010). This includes cases of local dominance that specifically arise with enzymes when fitness is a concave function of the activity level while the heterozygote's enzymatic activity is intermediate to that of both homozygotes (Gillespie and Langley 1974).

Here, equilibrium was tested through simulations under Levene's model to account for combinations of parameters leading to nontrivial evolution of allelic frequencies within a finite population. This approach is relevant since the underlying conditions of Levene's model perfectly fit the American eel's life cycle, which is characterized by random mating and dispersal, and a local density regulation (Vollestad and Jonsson 1988). While exploring a realistic range of parameter values, stable equilibrium was predicted at only two of eight tested loci. This relatively low proportion may be partly explained by uncertainties due to the methodological approach. For instance, a lack of precision in the estimation of fitness parameters, but also in the relative outputs among niches, will obviously affect the realism of the simulations (Schmidt and Rand 2001). Here, we considered only 16 river mouths among a much greater number of existing rivers harboring the American eel along the North Atlantic coast. Yet, those sampling locations are distributed evenly across the species range and are therefore representative of the variation in selection direction and intensity potentially encountered by glass eels. By considering only the earliest life stages, we may fail to catch differential selection acting later in the life cycle. While we cannot rule it out, the fact that most of the mortality occurs before entering freshwater (Bonhommeau *et al.* 2009) reduces this possibility. Moreover, it is likely that selection acting at later life stages plays on different sets of genes. Finally, successive waves of recruiting glass eels can face different conditions depending on their date of arrival (*i.e.*, sea-surface temperature), and interannual global variations in the selective parameters may also exist. The natural settings are thus likely more complex than considered in the model. However, it has been shown that temporal variation in selection is less efficient in maintaining locally adaptive polymorphisms compared to spatially varying selection (Ewing 1979).

Thus, it appears plausible that the low proportion of protected polymorphisms truly reflects the relatively restrictive conditions required for equilibrium (Levene 1953). When a locally advantageous allele appears by mutation and successfully escapes random loss when rare, it has more chance to invade the panmictic gene pool and to become fixed than to stabilize at an intermediate, stable frequency. Because the transitory phase to fixation will often last for a few hundred generations, loci that are undergoing incomplete selective sweeps may not be easily discovered unless they are frequent enough to be detected with a genome-scan approach. In populations with a large census size, however, new adaptive mutations can frequently occur (Karasov *et al.* 2010) and may result in selective sweeps if the overall effects of spatially varying selection are unbalanced. The finding that, in our simulations, the invading allele was always a derived state for each of the six predicted unstable SNPs supports the hypothesis of linkage with such a globally advantageous mutation that has not already reached fixation.

Incomplete sweeps are expected to leave a specific pattern in the haplotype structure. Because the derived allele increasing in frequency has an atypically long-range LD compared to neutral ancestral variants segregating at the same frequency (Sabeti 2006; Voight *et al.* 2006), the measure of LD can be used to detect ongoing directional selection. Here, sequence information retrieved from 454 sequencing data was insufficient to perform such tests on the basis of the haplotype structure, which require phased haplotypes extending outside the selected gene. However, measuring LD on the basis of available information within contigs revealed the existence of substantial linkage ($r^2 > 0.5$) between some sites that are likely separated by a few kilobases if the presence of introns is taken into account.

Implications for adaptation and conservation of American eel

The Gene Ontology (GO) molecular functions of the genes inferred to be involved in $G \times E$ interactions mostly encompassed major metabolic functions, among which are lipid metabolism (*ANX-2*, inhibition of phospholipase A2; *ACP*, acyl carrier activity; *GPX-4*, phospholipid–hydroperoxide glutathione peroxidase activity), saccharide metabolism (*MDH*, malate dehydrogenase activity; *UGP-2*, UDP-glucose pyrophosphorylase activity), and protein biosynthesis (*EIF-3F*, translation initiation factor; *PRP-40*, pre-mRNA–processing activity). The best predictive models of all these genes included temperature, a factor known to have a strong influence on the level of metabolism in the American eel (Walsh *et al.* 1983). Moreover, the center of the synthetic multilocus latitudinal cline coincided with the region where the warm waters of the Gulf Stream drift away from the coasts. Although the American eel occupies a wide latitudinal range, its thermal preferendum is rather elevated for the temperate zone, since glass eels have a highly reduced swimming ability below 7° (Wuenschel and Able 2008), elvers optimally grow at 28° (Tzeng *et al.* 1998), and yellow eels stop feeding and become metabolically depressed below 10° (Walsh *et al.* 1983). Therefore, selective effects are logically expected at the relatively low temperatures locally encountered between metamorphosis and recruitment to estuaries, although phenotypic plasticity may also account for the wide range of temperature tolerance in *A. rostrata* (Daverat *et al.* 2006).

Two genes involved in defense response were also detected (*CST*, cysteine endopeptidase inhibitor activity; *SN4-TDR*, nuclease activity). Since selective factors related to pathogen exposure do not always correlate with temperature or geographic coordinates, other genes whose variation patterns could not be explained with our set of explanatory variables may also play a role in resistance to pathogens in *A. rostrata*. For instance, the innate immune response gene *TRIM-35* showed strong departure from HWE in glass eels and atypically high levels of genetic differentiation between some localities (F_{ST} values up to 0.174). In parallel, simulating the evolution of allelic frequencies at this locus on the basis of observed genotype frequencies predicted a stable equilibrium (results not shown). This observation warrants further investigation, especially since the *TRIM-35* gene cluster, which is located in a region of significantly elevated nucleotide diversity in the threespine stickleback (*Gasterosteus aculeatus*), is also a candidate target of balancing selection in this species (Hohenlohe *et al.* 2010).

In conclusion, we have screened >13,000 SNPs in transcribed regions of the American eel genome and identified several genes undergoing spatially varying selection associated with the highly heterogeneous habitat used by this species. Due to our methodological approach, however, the number of genes involved in $G \times E$ interactions has likely been underestimated, and the causative agents of selection remain partially unknown. Nevertheless, the higher proportion of transient *vs.* stable polymorphisms suggests that locally adaptive polymorphisms are not easily maintained by spatially varying selection when local adaptation is impossible. Under such conditions, theory predicts that phenotypic plasticity, by broadening the environmental tolerance of individual genotypes, provides a more functionally adaptive response to spatial environmental variation (Sultan and Spencer 2002). Indeed, the costs induced by selection on locally adaptive traits are particularly severe in the case of random mating and in the absence of habitat choice (Lenormand 2002). For eels, as for other highly fecund marine species facing huge mortality rates during larval stages, phenotypic plasticity may represent the main mechanism for coping with habitat heterogeneity (Edeline 2007), and our results suggest that differential expression of paralogous genes may be involved in this regulation. Nevertheless, the finding of locally selected mutations spreading to fixation in *A. rostrata* suggests that this high census size species may be regularly subject to new locally adaptive mutations. How the recent population decline of Atlantic eels (Wirth and Bernatchez 2003) affects their adaptability to changing environments is still poorly understood and will be a matter of further investigations.

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The Genetic Consequences of Spatially Varying Selection in the Panmictic American Eel (*Anguilla rostrata*)

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File S1
Supporting Data

File S1 is available for download at http://www.genetics.org/content/suppl/2011/11/30/genetics.111.134825.DC1 as an Excel file.

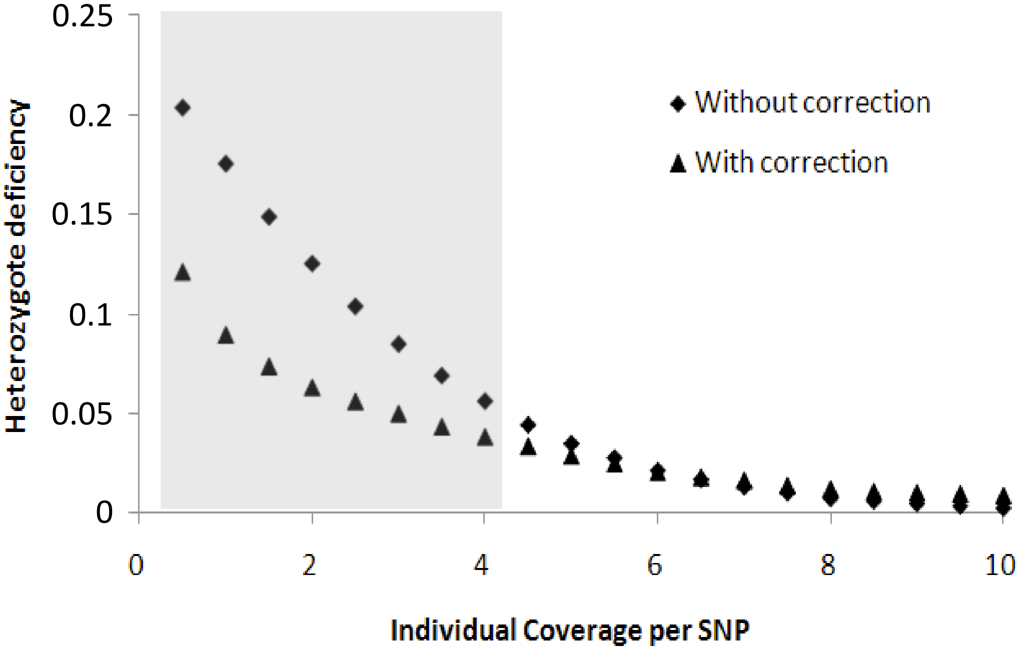


Figure S1 Correction for hidden heterozygotes: methodological validation on simulated datasets. Polymorphism data was simulated for 20 diploid individuals belonging to a panmictic population, at 10000 bi-allelic loci for which the allelic frequency spectrum was analytically derived from equation 51in Tajima (1989). Individual genotypes were drawn from a trinomial distribution with event probabilities (ρ^{2}; $2\rho(1-\rho)$; $(1-\rho)^{2}$), where ρ is the frequency of the *A* allele at a given locus. In order to reproduce the random sampling procedure of individual sequences in our high-throughput sequencing approach, uniform probabilities over individuals and loci were used to randomly draw a number of copies per locus per individual with a given targeted mean coverage. Knowing the number of sampled copies for each individual at each site, observed data were finally drawn using binomial sampling with event probabilities depending on individual genotype. Simulated data were first used to calculate the mean observed heterozygote deficiency per site. Our procedure to correct for heterozygote deficiency caused by limited coverage was then applied on simulated data to evaluate its efficiency. Results are presented for a series of simulated datasets characterized by a mean individual coverage value ranging from 0.5 to 10×. The grey domain represents the individual coverage interval in which most *in silico* SNPs lied in our study.

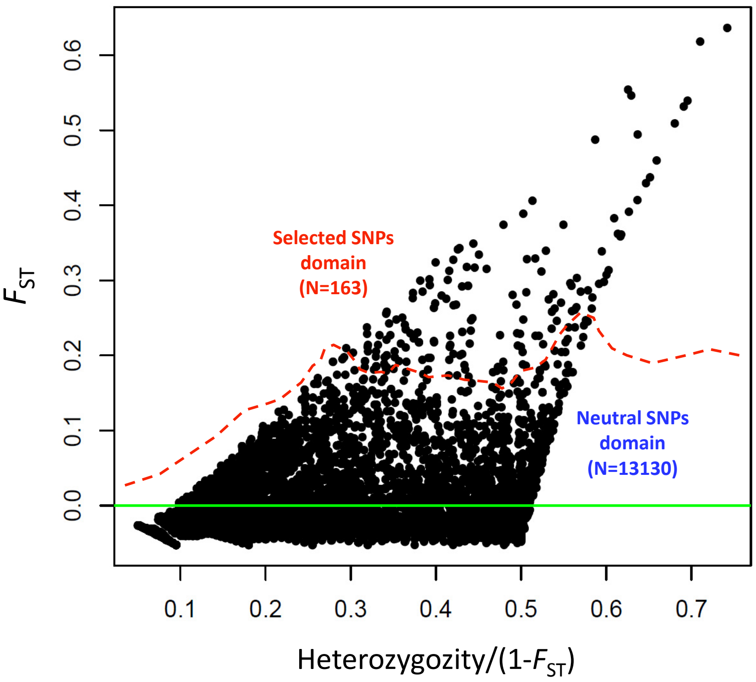


Figure S2 Joint distribution of F_{ST} values and (heterozygosity within samples)/(1-F_{ST}) estimated between samples RB and FL for the 13293 *in silico* SNPs. The green solid line shows the expected F_{ST} value under panmixia and the red dashed line represents the 99.5% quantile of the distribution of simulated F_{ST} obtained under a neutral model assuming near panmixia.

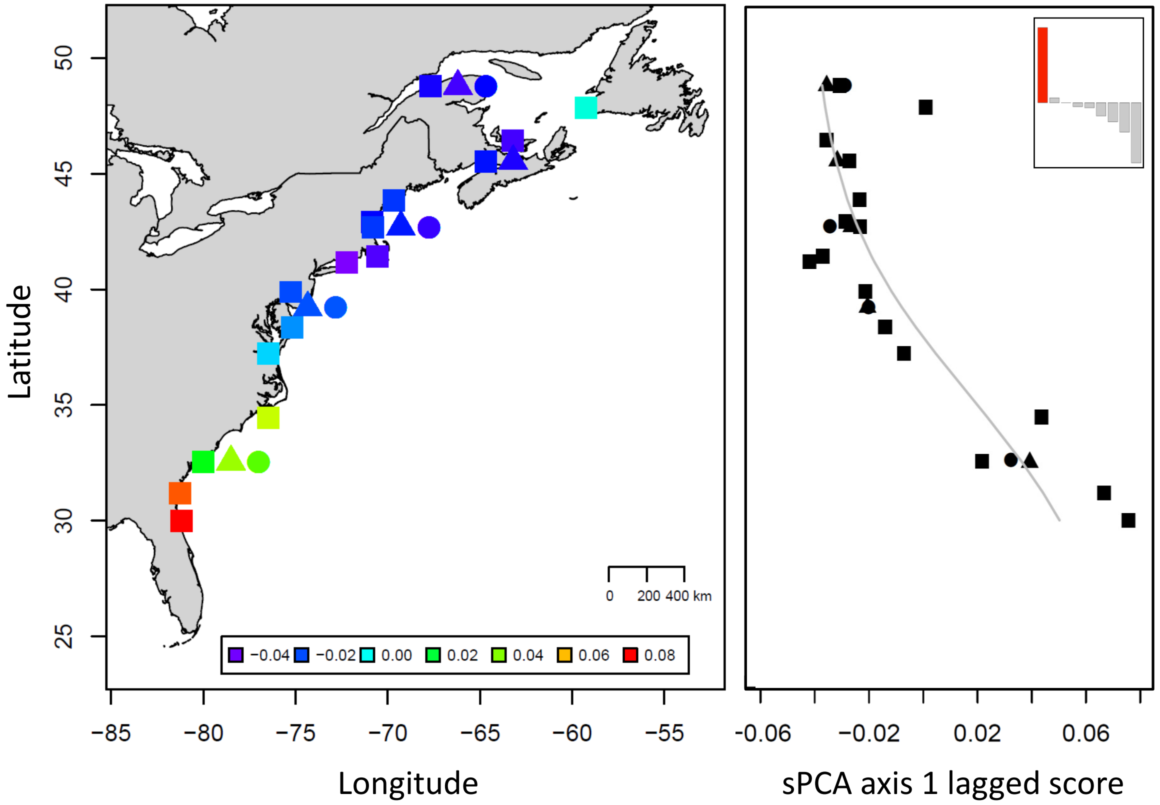


Figure S3 Temporal stability of the synthetic multilocus latitudinal cline over 3 continental categories. Squares represent locality samples from the *GLASS8* category, circles those from the *OYO9* category and triangles those from the *GLASS9* category. The analysis was based on genetic variation at the 8 loci significantly associated with explanatory variables in the *GLASS8* category. Colors are scaled to the lagged scores of the first principal component, as indicated in the caption. The plot on the right shows the shape of the synthetic multilocus cline over the three continental categories, as well as the decomposition of the product of the variance and the spatial autocorrelation into positive, null and negative components (upper right corner). The clinal structure corresponds to the highly positive eigenvalue in red.

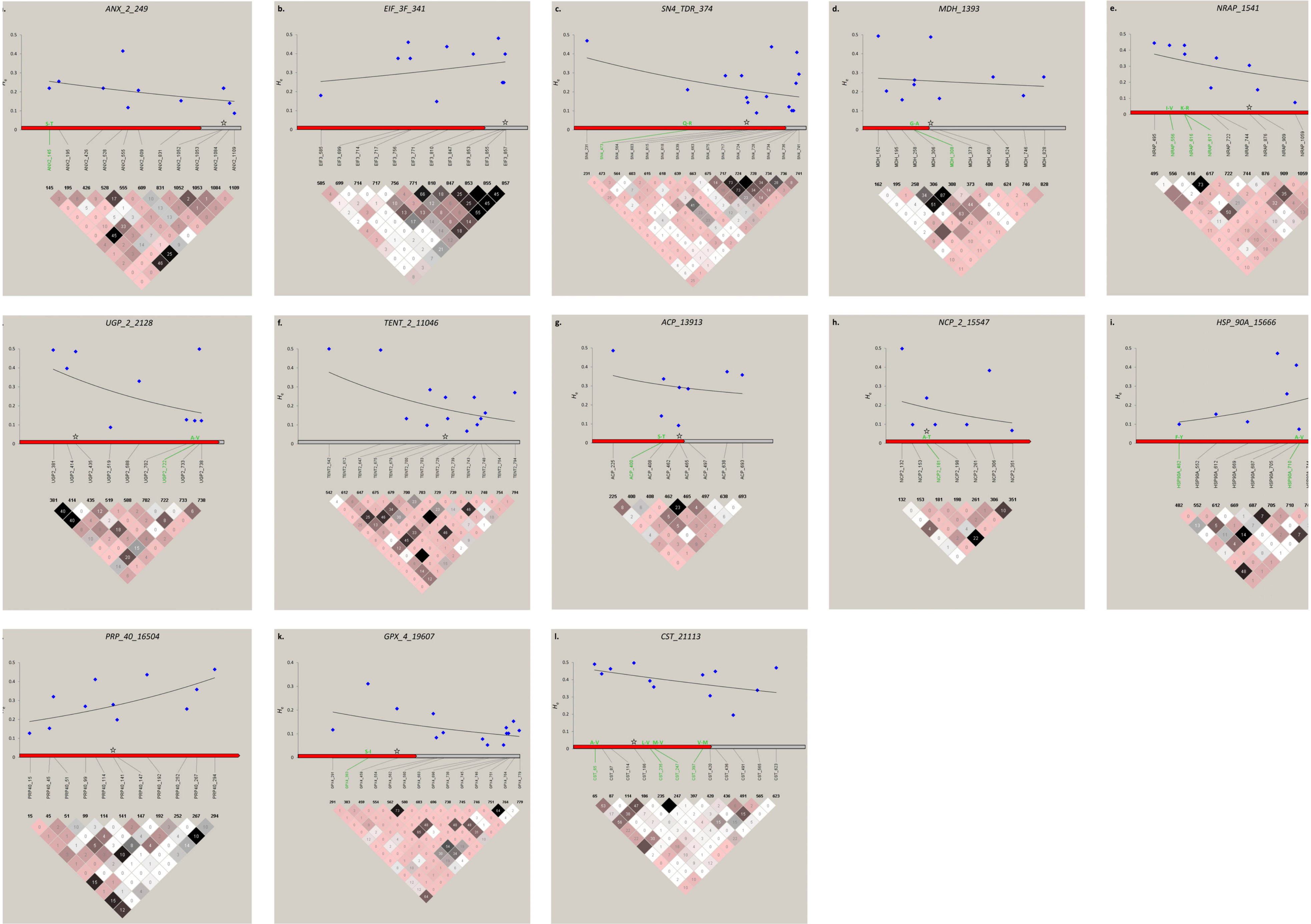
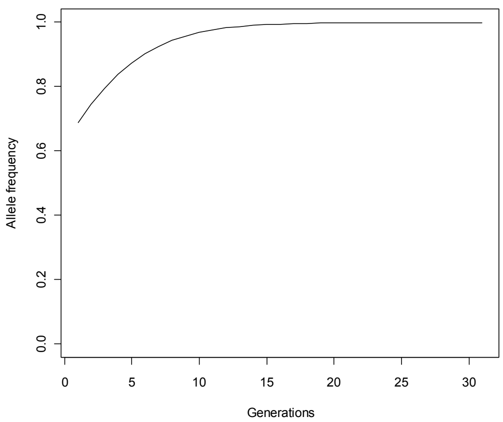
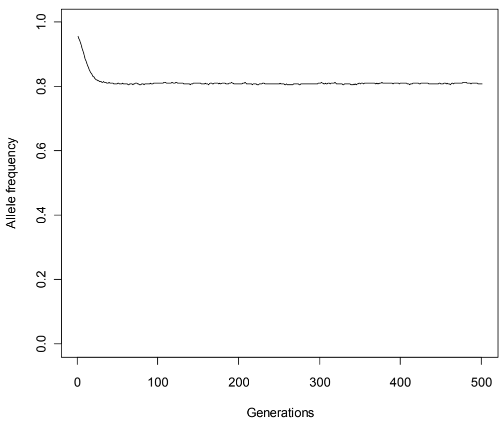
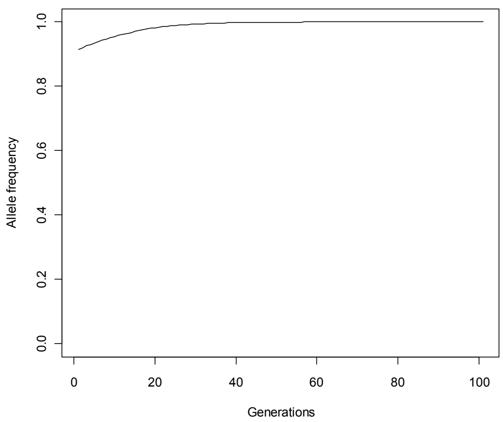
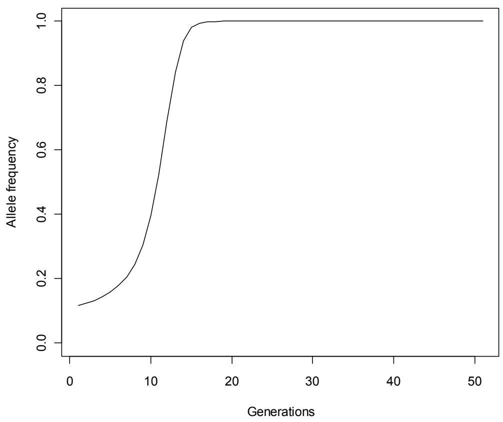

ANX_2_249
b.
EIF_3F_341
c.
SN4_TDR_374
d.
MDH_1393
e.
NRAP_1541
UGP_2_2128
f.
TENT_2_11046
g.
ACP_13913
h.
NCP_2_15547
i.
HSP_90A_15666
PRP_40_16504
k.
GPX_4_19607
l.
CST_21113
H_e
S-T
Q-R
G-A
I-V
K-R
A-V
S-T
A-T
F-Y
A-V
S-I
A-V
L-V
M-V
V-M

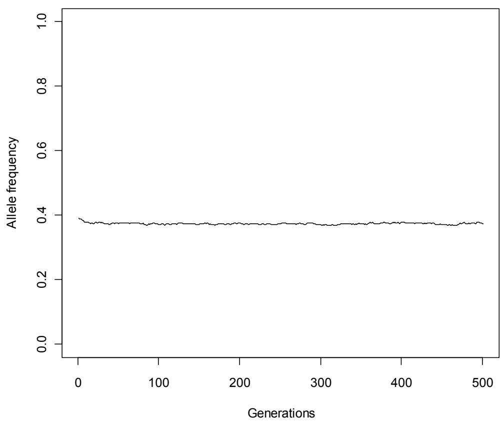
Figure S4 Expected heterozygosity and linkage disequilibrium structure along the sequenced transcribed region for each of the 13 genes associated with explanatory variables. Blue diamonds correspond to values of H_e, showed with a fitted exponential curve. Each square in the triangular matrix represents the level of LD calculated between a pair of polymorphic sites, which position in the gene has been indicated above the matrix. The color indicates the level of LD based on the D' statistic (white for no linkage, shades of pink for intermediate levels of LD and black for strong LD) and the r^2 value (given as a percentage) is displayed for each pair of SNPs. Variable sites in green represent amino-acid polymorphisms in the coding gene regions shown in red. The focal SNP showing significant association with explanatory variables is indicated by a star symbol.

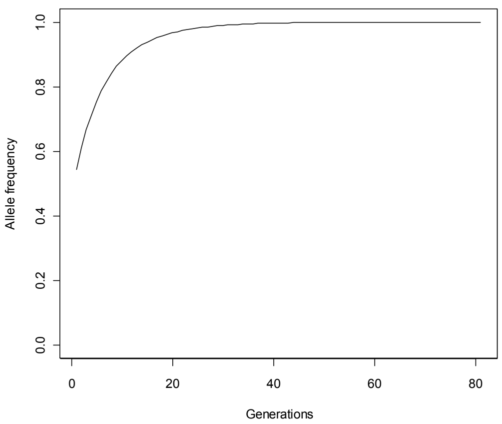

ACYL_13914

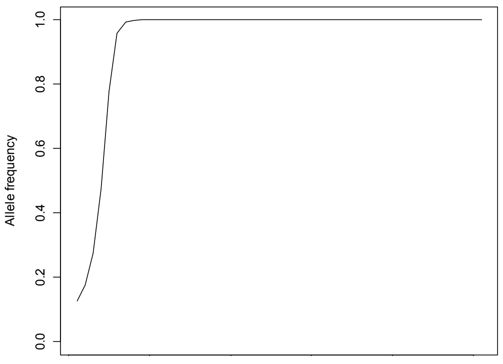

ANX_2_249


GPX_4_19607


HSP_90A_15666


MDH_1393


NRAP_1541


PRP_40_16504

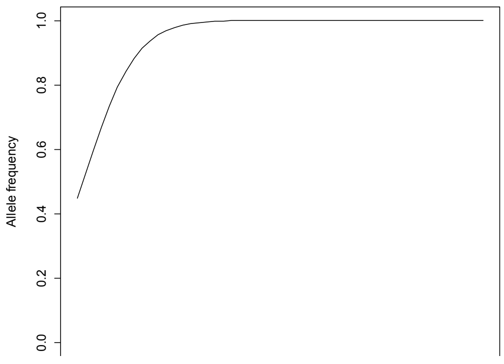

UGP_2_2128

Figure S5 Simulated evolution of allelic frequencies at each of the 8 loci statistically associated with explanatory variables in the *GLASS8* category. Uniform contribution among niches and a population effective size of 10^5 are assumed.

Table S1 Locus name, gene annotation, contig length, BLASTX e-value and variation type for each of the 73 genotyped SNPs.

Locus	Gene	Contig length	Blastx e-value	SNP
40S_S18_1401	40S ribosomal protein S18	413	3.00E-73	A/G
60S_L10A_21874	60S ribosomal protein L10a	437	3.00E-48	A/G
60S_L27A_12416	60S ribosomal protein L27a	890	3.00E-52	C/T
ACTB_21752	Beta-actin	1005	1.00E-170	C/T
ACT_A3B_8646	Actinin alpha 3b	838	6.00E-150	C/T
ACP_13914	Acyl carrier protein, mitochondrial precursor	718	5.00E-57	A/G
ADH_3_533	Alcohol dehydrogenase class-3	707	3.00E-19	C/T
ADSS_L1_15447	Adenylosuccinate synthetase isozyme 1	325	2.00E-42	C/T
ALDH_2_16634	Aldehyde dehydrogenase 2	567	7.00E-91	C/T
ALD_R_2449	Aldose reductase	362	3.00E-48	A/C
ANK_R_13478	Ankyrin repeat domain-containing protein 1	1212	3.00E-96	A/T
ANN_A11_16176	Annexin A11	1097	2.00E-82	C/G
ANX_2_249	Annexin A2-A	1082	2.00E-127	A/G
ARF_4_18099	ADP-ribosylation factor 4	455	4.00E-35	C/T
ATP_BC_212	ATP-binding cassette sub-family A member 1	1145	1.00E-121	C/G
BPNT_1_18778	3'(2'),5'-bisphosphate nucleotidase 1	331	3.00E-39	A/C
CLIC_5_10148	Chloride intracellular channel 5	390	2.00E-49	C/G
COI_17591	Cytochrome oxidase subunit I, mitochondrial	601	1.00E-62	C/T
COP_9_18132	26S protease regulatory subunit 7	569	7.00E-68	A/G
CSDE_1_11069	Cold shock domain-containing protein E1	1505	0	G/T
CSDE_1_19713	Cold shock domain-containing protein E1	1623	0	C/G
CST_21113	Cystatin precursor	722	2.00E-33	A/G
CYT_BC1_9061	Cytochrome b-c1 complex subunit 2, mitochondrial precursor	852	4.00E-95	G/T
EF2_10494	Translation elongation factor 2	2190	0	C/G
EF_1G_4796	Translation elongation factor 1 gamma	484	2.00E-65	C/T
EIF_3F_341	Translation initiation factor 3 subunit F	902	4.00E-137	C/T
EIF_3J_11587	Translation initiation factor 3 subunit J	890	8.00E-41	A/T
FER_H_20955	Ferritin heavy subunit	1152	7.00E-98	G/T
GAPDH_20355	Glyceraldehyde-3-phosphate dehydrogenase	1223	0	C/T
GDE1_2508	Glycerophosphocholine phosphodiesterase	1127	3.00E-147	A/G
GOG_B1_15792	Golgin subfamily B member 1	457	2.00E-29	A/G
GPX_4_19607	Glutathione peroxidase 4	895	1.00E-90	C/T
HMG_T_9973	High mobility group-T protein	1131	2.00E-80	A/G
HSPE_1_17854	10 kDa heat shock protein, mitochondrial	410	2.00E-44	A/G
HSP_90A_15666	Heat shock protein 90 alpha	1108	1.00E-160	C/T
HSP_90B_21100	Heat shock protein 90 beta	1131	2.00E-118	C/T

IF_RF2_19747	Interferon regulatory factor 2	334	2.00E-51	C/T
JAM_3_13916	Junctional adhesion molecule 3b	474	7.00E-58	C/T
KRT_12_20618	Keratin 12	884	2.00E-104	A/G
KRT_A_15738	Keratin alpha-like	847	7.00E-44	A/G
LDH_B_9441	Lactate dehydrogenase B	1528	1.00E-159	A/G
MDH_1393	Malate dehydrogenase, mitochondrial precursor	918	3.00E-56	C/G
MYH_14857	Superfast myosin heavy chain	1204	1.00E-107	C/T
NADH1_10_21119	NADH dehydrogenase 1 alpha subcomplex subunit 10	894	9.00E-88	C/T
NADH_4_21742	NADH dehydrogenase subunit 4, mitochondrial	1221	1.00E-141	A/G
NADH_5_17101	NADH dehydrogenase subunit 5, mitochondrial	2823	0	G/T
NCP_2_15547	Nucleolar complex protein 2	424	3.00E-62	A/G
NEX_19953	Nexilin	802	4.00E-33	C/T
NGD_21138	Neuroguidin	365	2.00E-35	G/T
NRAP_1541	Nebulin-related anchoring protein	1624	2.00E-145	C/T
PA2G4_2600	Proliferation-associated protein 2G4	1211	0	C/G
PFN_15113	Profilin-2	687	4.00E-16	G/T
PGD_18096	6-phosphogluconate dehydrogenase, decarboxylating	486	6.00E-54	A/G
PGI_1	Phosphoglucose isomerase-1	927	9.00E-76	A/G
PGI_2_1862	Phosphoglucose isomerase-2	1953	1.00E-130	C/T
PGK_1_11454	Phosphoglycerate kinase 1	1136	1.00E-106	A/G
PRP_40_16504	Pre-mRNA-processing factor 40 homolog A	585	7.00E-29	C/G
PSA_4_21534	Proteasome subunit alpha type-4	978	2.00E-122	C/T
RFC_3_18186	Replication factor C subunit 3	359	2.00E-38	C/G
RTF_1_21288	RNA polymerase-associated protein RTF1 homolog	655	2.00E-38	G/T
SLC_25A5_19808	ADP/ATP translocase 2	991	1.00E-153	C/T
SM_22_6449	Transgelin	775	5.00E-112	C/T
SN4_TDR_374	Staphylococcal nuclease domain-containing protein 1	1248	8.00E-119	C/G
TENT_02_11046	No hit	884	-	G/T
TENT_03_12589	Collagen type XXVIII alpha 1 a	275	2.00E-26	C/T
TENT_05_19704	No hit	400	-	C/G
TENT_06_16512	Protein phosphatase regulatory subunit	410	2.00E-04	G/T
TRIM_35_8416	Tripartite motif-containing protein 35	771	1.00E-81	A/G
TTN_B_20952	Titin b	884	4.00E-127	C/T
TUB_A_19211	Tubulin alpha 2	733	5.00E-67	C/T
UBI_A52_5049	Ubiquitin A-52 residue ribosomal protein fusion product 1	715	5.00E-66	A/G
UGP_2_2128	UDP-glucose pyrophosphorylase 2	824	2.00E-129	C/G
ZETA_15177	Tyr 3-monooxygenase/Trp 5-monooxygenase activation protein	724	2.00E-54	A/G

Table S2 List of the KASPar primers used for the 73 individual SNP assays.

Locus	Primer Allele X	Primer Allele Y	Common Primer	Allele X	Allele Y
40S_S18_1401	CCAGAAGTGCCGGAGACCG	CCCAGAAGTGCCGGAGACCA	AGGATCTGGAGAGGCTGAAGAAGAT	G	A
60S_L10A_21874	CCCAGGCCCAAGTTCTCC	ACTCCCAGGCCCAAGTTCTCT	GCCTCATCACAGTGCTGCTGGT	G	A
60S_L27A_12416	GGAGCTTGTGTGCTMATGGCG	GGAGCTTGTGTGCTMATGGCA	TTTTAAACATTTATTCCTGCAAAAA	C	T
ACTB_21752	CACCATCGGCAACGAGCGC	ATCACCATCGGCAACGAGCGT	GGGCCTCGGGGCAACGGAA	C	T
ACT_A3B_8646	AACACTGCGTTCGAGGTGGCT	CACTGCGTTCGAGGTGGCC	ACATCTTGGGGATGTCCAGGTACTT	T	C
ACP_13914	ACATCGCAGACAAGAAAGACGTC	GTACATCGCAGACAAGAAAGACGTT	GTGGGGAGGCCCCGTTATTCAT	G	A
ADH_3	AGGCAGAACTGCCAGTTGACTC	ATAAGGCAGAACTGCCAGTTGACTT	CCCCAATGACCCTGACATGTATGAA	C	T
ADSS_L1_15447	GGAGACGGCTTTGGAGTTGATAATT	GAGACGGCTTTGGAGTTGATAATC	AGTGGTTGAYGGGAAGGAATATGACTT	T	C
ALDH_2_16634	GGCTACAAGGCCTCTGGGAAT	GGCTACAAGGCCTCTGGGAAC	CGGTGTAGTTGTCCAGGCCRTATT	T	C
ALD_R	GGACGCCGGGCTGGTCA	GGACGCCGGGCTGGTCC	CGGTTGAAGTTGGAGAYCCCGAT	A	C
ANK_R_13478	TTATTCTCACAGCGTCGTGCAGA	TATTCTCACAGCGTCGTGCAGT	CGCCAAAGACATGGACGGAGACA	A	T
ANN_A11_16176	CGTGTACAGAGACTTCTGGTAGG	CGTGTACAGAGACTTCTGGTAGC	GACATCCGCCAGGAGTAYGTGAA	G	C
ANX_2_249	GTAGCGCAATGGGGAGGGG	CAGTAGCGCAATGGGGAGGGA	GCTGTCCTCGTCACCCTGTCAT	G	A
ARF_4_18099	CACAGCCTCCCTCAGCTCG	GCACAGCCTCCCTCAGCTCA	RCTGCTGAAAATGCTGCAGGAGGA	C	T
ATP_BC_259	GAAGGAAGCCGTGGTGGACC	GAAGGAAGCCGTGGTGGACG	TGGCCTTCTCGTCCTGCAGGAA	G	C
BPNT_1_18778	ACATCCACGGGAAGACGTACC	GACATCCACGGGAAGACGTACA	TGTGCTTGACGTCCGCGTCGTA	C	A
CLIC_5_10148	CGTGCGCRTTCTGCAGGTAC	CGTGCGCRTTCTGCAGGTAG	ACTTCGAGATCCCGGCGGAGAT	C	G
COI_17591	GCCGGAGCATCTGTTGACCTG	GCCGGAGCATCTGTTGACCTA	GAGATACCTGCAAGGTGAAGTGAGAA	C	T
COP_9_18132	GATACATGACCTACAACTAAGCAACG	AGATACATGACCTACAACTAAGCAACA	AAAGAAAACGTATAACCGAGCRCAATCAAA	G	A
CSDE_1_11069	GGCAGGATGTCGATGTTGGTG	GGGCAGGATGTCGATGTTGGTT	CCACCGACCGGCGGGACAA	G	T
CSDE_1_19713	CCATGTAGAAGCTGACTTTGTCG	CCATGTAGAAGCTGACTTTGTCC	CCTGACGTACACGTCCGAGGAT	C	G
CST_21113	GTCACTTTGCTGACGAACAAAGCA	CACTTTGCTGACGAACAAAGCG	CGTCCAGGTCAACCTCAAGAGCAA	A	G
CYT_BC1_9061	GGGAGATGGTGTACACTCCAAAC	GGGAGATGGTGTACACTCCAAAA	CAGTGCATCTGCATTCAATGCCAGTT	G	T
EF2_10494	CCGGACTCCTCGCTCACC	CCGGACTCCTCGCTCACG	AATCGGACCCGGTGGTGTCCTA	C	G
EF_1G_4796	GATGCAGGTCACAAACCAGCGT	ATGCAGGTCACAAACCAGCGC	CATTCCGTCAGCCCTTCCCCAA	T	C

EIF_3F_341	GAGCAGAAGCTCACTTATATGTTTCTT	AGCAGAAGCTCACTTATATGTTTCTC	ACTTCACGCTTTTATTCAGTAGAGCCATA	T	C
EIF_3J_11587	AATGCACAGATCGTTCGTACTGAGA	AATGCACAGATCGTTCGTACTGAGT	CACGGATTTGCATAAGTTGCTTAAAGAGAA	T	A
FER_H_20955	CGCCTGCCCTGGACGGAA	CGCCTGCCCTGGACGGAC	GTGACGTCCCCGCRAAGCCAT	T	G
GAPDH_20355	CCACCCACGGACGTTTCCAC	CCACCCACGGACGTTTCCAT	GAGCTTTCCGCCTTCGGCCTT	C	T
GDE1_2508	GGAGCGGGTGCTTCAGAGC	GGGAGCGGGTGCTTCAGAGT	CCCACCAGCCCRGGGAGAA	G	A
GOG_B1_15792	CAAATCCCGCTACCTGTTCCTCA	AAATCCCGCTACCTGTTCCTCG	GASAACGTGTAACGCCAGCAGGTA	A	G
GPX_4_19607	CACTTGGGTCCTGCAGTGGC	CACTTGGGTCCTGCAGTGGT	CAGAGAGGGAAAGGTTGTGAAAAGATATT	C	T
HMG_T_9973	GCAAGTTCGAGGACTTGGCGAAA	CAAGTTCGAGGACTTGGCGAAG	TGTAGTTCTTCATCTCCCGCTCGTA	A	G
HSPE_1_17854	TACCCGAATATGGAGGAACTAAAGTT	ACCCGAATATGGAGGAACTAAAGTC	GGAAGTAGTCCTTGTCCTCCAGAAT	A	G
HSP_90A_15666	GTTCTTTCCCTCTTTTGTGTCCTCA	CTTTCCCTCTTTTGTGTCCTCG	CCCCAGATTGAGGAYGTGGGAT	T	C
HSP_90B_21100	GGAGAAGGAGAAAGAGGAGGAC	AGGAGAAGGAGAAAGAGGAGGAT	CCACGTCCTCGATCTTGGGCTT	C	T
IF_RF2_19747	GTGAATGGCCCAGTTTCGGAAC	GTGAATGGCCCAGTTTCGGAAT	GACGTGGAGAAAGACGCACCYTT	C	T
JAM_3_13916	AAGTAGCCCCGTTTATACGCACAA	GTAGCCCCGTTTATACGCACAG	GTGGTGGTGGTTCTCCTGTGTATAA	T	C
KRT_12_20618	GGAACCAGTTCTCCCATTCCTTC	GGAACCAGTTCTCCCATTCCTTT	CAGTACGAGGGAATGGCCGACAA	G	A
KRT_A_15738	CCCTTCTCCACTTTGCCCAC	CCCCTTCTCCACTTTGCCCAT	CTCATCCCACTGGGAGACCAGAA	G	A
LDH_B_9441	ACATCCATCACATCTACACTCCC	CTACATCCATCACATCTACACTCCT	AGTGTAGCAGTAAMGGTAGAACAGAGT	G	A
MDH_1393	AATTAATGAGGTCTTAATTTGGCTGCC	AATTAATGAGGTCTTAATTTGGCTGCG	GAGGACTTTGTACAGAACATGAAATGAGAA	C	G
MYH_14857	TTGGTTCTGTGTTTTGAGCTCA	CTTTGGTTCTGTGTTTTGAGCTCG	GGTGGAGGTCTCTGAGAGACACAA	T	C
NADH1_10_21119	GCACAATCAATGAGATATAACTTATTTGTTAAT	CACAATCAATGAGATATAACTTATTTGTTAAC	GYTTTCCTTTCCTCTGATCCTGTTCTA	T	C
NADH_4_21742	GATGATACTAGTCCGTGGGCAATT	ATGATACTAGTCCGTGGGCAATC	CCCATGAGGATTYACAGGAGCAATTAT	A	G
NADH_5_17101	CAACTATTCATTGGCTGAGAAGGC	TCAACTATTCATTGGCTGAGAAGGA	CGTATCATCAYCCAATTAGGAGAAATGATA	G	T
NCP_2_15547	GATCTGCCGGCACAAGCAGG	AAGATCTGCCGGCACAAGCAGA	GCTTGAGGACGGGGTTGAGGTA	G	A
NEX_19953	CCTCCTCCAGTCGCCGC	CTCCTCCTCCAGTCGCCGT	GAGGGCTGAAGAGGAGGCCAA	C	T
NGD_21138	ATGACATTCCCAGCATGCCTCG	GATGACATTCCCAGCATGCCTCT	TCGCCGAGAGAAAAGTAAGCGGAA	G	T
NRAP_1541	CTTGGCGTGCTGGAAGTCA	CTCTTGGCGTGCTGGAAGTCG	CCAGGAGACCTGCTCYCATTACAA	T	C
PA2G4_2600	AAACTCACCCTCCTTCTCGTGG	AAACTCACCCTCCTTCTCGTGC	ACGAGCTGCTGCAGCCCTTCAA	C	G
PFN_15113	CAAACAGGCTATCGCGGTCATG	GCAAACAGGCTATCGCGGTCATT	AGAGGAGGTCCAGGTGCTGCA	G	T
PGD_18096	CCCGGGTTCGACAGAAGCTCA	CCGGGTTCGACAGAAGCTCG	GGGATTATTTTGGYGCGCACACCTA	A	G

PGI_1	CCTCCACCAACGGGCTCATCA	CTCCACCAACGGGCTCATCG	TGGAGCTCARGCGTAGTTTTTCTTGAT	A	G
PGI_2_1862	ACATGCACCGCTTTGCTGCC	GTACATGCACCGCTTTGCTGCT	GATTCCATGTCTCCCTGCTGGAAAT	C	T
PGK_1_11454	GGGCGAAGTTGTCCCACTCA	GGGCGAAGTTGTCCCACTCG	ACGGGCCGGTCGGCGTGTT	A	G
PRP_40_16504	AGAGTGACGTCCTCAAAGGCC	AGAGTGACGTCCTCAAAGGCG	TGCGGGAGAGATTCCTGAAGGAAT	G	C
PSA_4_21534	GGAGGAGGGACACCAGAGGA	GAGGAGGGACACCAGAGGG	GGACAAGAAGGAGAAGGAGCAGAAA	T	C
RFC_3_18186	AAGAAAACGCGGATCATGTGTCTG	AAGAAAACGCGGATCATGTGTCTC	CGGGTCCGTACAGCTCGCGTA	G	C
RTF_1_21288	GATGGGGGACGAGGAGGACA	ATGGGGGACGAGGAGGACC	GCTCCCTCTCCTTCTCCGTCAT	T	G
SLC_25A5_19808	ACAGTGTCGAAGGGGTAGGAC	GACAGTGTCGAAGGGGTAGGAT	CTCACATTGTGGTCAGCTGGATGAT	C	T
SM_22_6449	AGAGGGGCGTCCCAAGCG	CAGAGGGGCGTCCCAAGCA	GGGGTCGRCCATATCCTGTCATT	C	T
SN4_TDR_374	GAACTCGTCGGCGTCGTCC	GAACTCGTCGGCGTCGTCG	GAACATCTGGCGTTACGGRGACTT	C	G
TENT_02_11046	CGAGAAAATCACATGACCTGTCC	GTCGAGAAAATCACATGACCTGTCA	ACACAAACATGTTCTCAGCAAACATKCT	G	T
TENT_03_12589	GTCTGGCCACTCGTCCG	GTCTGTCTGGCCACTCGTCCA	AAGGGARGCGCACTTCCTGTGAAA	C	T
TENT_05_19704	CCTTGTGAATCGCTCGACGCC	CCTTGTGAATCGCTCGACGCG	GTTAGCTCAGTGTTGTCAGAGCAGAA	G	C
TENT_06_16512	TCTGTTTTGGTCATTTCCCTGATTTC	CTTCTGTTTTGGTCATTTCCCTGATTTA	CTGTCAATCAACGTGATTATGCACCTTAT	G	T
TRIM_35_8416	GKTTGAGATCCCCGCACTACTA	GAGATCCCCGCACTACTG	GGCACTGGCACTGCCCARAGTA	A	G
TTN_B_20952	ACATAATAATCCAAACCTTCATGAACAAC	GTACATAATAATCCAAACCTTCATGAACAAT	CCTTTAGCATTTGGACCTCAGATTGAA	C	T
TUB_A_19211	GGGATCACTCTTGTCTGTCTTTCAAA	GGATCACTCTTGTCTGTCTTTCAAG	CCCTTGAAGCAGGATAGTATAAGACATTT	T	C
UBI_A52_5049	GGGAGGGCTCAATGATCCCG	AGGGAGGGCTCAATGATCCCA	AGAGTCCACCCTCCACCTGGTA	G	A
UGP_2_2128	CCCGACACAATCTTGTTCTCCAA	CCCGACACAATCTTGTTCTCCAG	TCGACATTCCGGCAGGAGCCAT	T	C
ZETA_15177	AGGAATGGAGAAGTGTAAAAAGGTTTC	AATAGGAATGGAGAAGTGTAAAAAGGTTTT	GCACACCGACTCYTCTGCCAAA	G	A

Table S3 Results of within-category tests for Hardy-Weinberg Equilibrium, for each of the 70 diploid loci. Significant *p*-values after correcting for False Discovery Rate are shown in bold.

Locus Name	p-value *SAR7*	p-value *GLASS8*	p-value *0Y09*	p-value *GLASS9*
40S_S18_1401	1.00000	0.12154	0.22574	0.18342
60S_L10A_21874	1.00000	1.00000	1.00000	1.00000
60S_L27A_12416	1.00000	0.33219	0.73350	0.28553
ACTB_21752	1.00000	0.91921	0.01548	0.43163
ACT_A3B_8646	1.00000	0.21700	0.36195	1.00000
ACP_13914	1.00000	0.13962	0.33264	0.09231
ADH_3	1.00000	**0.00088**	**0.00003**	**0.00700**
ADSS_L1_15447	1.00000	0.01291	0.69547	1.00000
ALDH_2_16634	0.76938	0.37673	0.43921	0.42038
ALD_R	1.00000	0.12263	0.52380	0.44679
ANK_R_13478	1.00000	0.10961	0.27621	0.78760
ANN_A11_16176	1.00000	1.00000	1.00000	1.00000
ANX_2_249	0.06563	**0.00000**	**0.00052**	**0.00000**
ARF_4_18099	0.40586	0.18323	0.47020	1.00000
ATP_BC_259	0.22725	0.77055	0.31773	0.11295
BPNT_1_18778	0.59720	0.22555	0.13523	0.55784
CLIC_5_10148	0.18338	0.10316	0.76834	1.00000
COP_9_18132	1.00000	**0.00743**	0.32456	0.01337
CSDE_1_11069	1.00000	1.00000	0.76649	0.75550
CSDE_1_19713	0.14806	0.13634	0.02794	0.85559
CST_21113	0.77052	0.30015	0.72836	0.28627
CYT_BC1_9061	0.02557	0.27349	0.59605	0.47821
EF2_10494	1.00000	**0.00251**	0.59933	0.36706
EF_1G_4796	0.04617	0.42028	0.80844	1.00000
EIF_3F_341	0.42879	**0.00000**	**0.00000**	**0.00000**
EIF_3J_11587	1.00000	**0.00000**	**0.00107**	0.06416
FER_H_20955	0.77235	0.73993	0.30569	0.22289
GAPDH_20355	1.00000	0.05372	0.78629	0.80586
GDE1_2508	1.00000	0.72005	1.00000	0.23356
GOG_B1_15792	1.00000	0.14666	1.00000	0.64949
GPX_4_19607	1.00000	0.07780	1.00000	0.61542
HMG_T_9973	1.00000	0.13886	0.15097	1.00000
HSPE_1_17854	1.00000	0.22323	**0.00423**	0.26826
HSP_90A_15666	1.00000	0.02031	0.13498	0.36947

HSP_90B_21100	1.00000	**0.00000**	0.03145	**0.00377**
IF_RF2_19747	1.00000	0.37954	0.32440	1.00000
JAM_3_13916	1.00000	0.26091	0.45007	1.00000
KRT_13_20618	0.55548	0.55728	0.73019	0.87970
KRT_A_15738	1.00000	0.34404	0.26751	0.21900
LDH_B_9441	0.17316	0.34342	0.28692	0.68452
MDH_1393	0.01533	**0.00000**	0.02062	**0.00004**
MYH_14857	1.00000	0.59054	0.13159	0.33182
NADH1_10_21119	0.55818	0.32853	0.85564	0.87103
NCP_2_15547	0.25037	0.43750	0.25974	0.29391
NEX_19953	1.00000	**0.00001**	0.50013	0.05036
NGD_21138	0.51549	0.93132	0.48016	0.09074
NRAP_1541	0.56025	0.86245	0.47515	1.00000
PA2G4_2600	1.00000	0.03592	0.82994	0.05108
PFN_15113	0.59641	0.06795	1.00000	0.20738
PGD_18096	1.00000	0.27249	1.00000	1.00000
PGI_1	1.00000	0.29650	1.00000	0.46539
PGI_2_1862	1.00000	0.60288	0.60697	0.28459
PGK_1_11454	0.72955	0.50605	0.66184	1.00000
PRP_40_16504	1.00000	**0.00000**	0.76832	**0.00297**
PSA_4_21534	0.35604	0.09737	1.00000	0.63642
RFC_3_18186	1.00000	**0.00000**	**0.00014**	**0.00000**
RTF_1_21288	1.00000	0.50433	0.86476	0.35549
SLC_25A5_19808	1.00000	1.00000	0.61536	0.12976
SM_22_6449	0.24624	0.21508	0.61504	0.64701
SN4_TDR_374	0.25699	0.74257	1.00000	0.88096
TENT_02_11046	1.00000	**0.00009**	0.28272	0.62585
TENT_03_12589	0.24050	0.10899	1.00000	0.07961
TENT_05_19704	**0.00022**	**0.00000**	**0.00146**	**0.00012**
TENT_06_16512	1.00000	0.11943	0.70400	1.00000
TRIM_35_8416	0.14543	**0.00034**	0.22324	**0.00645**
TTN_B_20952	1.00000	0.81825	1.00000	0.39884
TUB_A_19211	0.76482	0.67939	0.85889	1.00000
UBI_A52_5049	0.21575	0.30265	0.53210	0.13803
UGP_2_2128	0.14211	**0.00000**	0.06281	**0.00036**
ZETA_15177	0.09160	0.59273	1.00000	1.00000

Table S4 Simulated evolution of allelic frequencies at the 8 loci statistically associated with explanatory variables in the *GLASS8* category under different assumptions. Models of relative contribution among niches are uniform contribution (C_UNI), normal distribution centered on the 8th and 9th niches with a variance of 10 (C_N_10), 6 (C_N_6), 4 (C_N_4), 3 (C_N_3), 2 (C_N_2) and 1 (C_N_1). The three population effective sizes considered were 10^4, 10^5 and 10^6. Evolution of allelic frequencies was simulated using relative fitness values either predicted from modeled or observed allelic frequencies.

Locus	Allele frequencies to estimate relative fitness	Population size	Models of relative niche contributions					
			C_UNI	C_N_10	C_N_6	C_N_4	C_N_3	C_N_2
ACP_13914	Modeled	10000	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 40 G
	Modeled	100000	Fix. < 20 G	Fix. < 20 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G
	Modeled	1000000	Fix. < 20 G	Fix. < 20 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G
	Observed	10000	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G
	Observed	100000	Fix. < 20 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G
	Observed	1000000	Fix. < 20 G	Fix. < 20 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G
ANX_2_249								
	Modeled	10000	**Equ. 0.81**	**Equ. 0.805**	**Equ. 0.80**	**Equ. 0.79**	**Equ. 0.78**	**Equ. 0.77**
	Modeled	100000	**Equ. 0.81**	**Equ. 0.805**	**Equ. 0.80**	**Equ. 0.79**	**Equ. 0.78**	**Equ. 0.77**
	Modeled	1000000	**Equ. 0.81**	**Equ. 0.805**	**Equ. 0.80**	**Equ. 0.79**	**Equ. 0.78**	**Equ. 0.77**
	Observed	10000	**Equ. 0.68**	**Equ. 0.68**	**Equ. 0.68**	**Equ. 0.68**	**Equ. 0.68**	**Equ. 0.69**
	Observed	100000	**Equ. 0.68**	**Equ. 0.68**	**Equ. 0.68**	**Equ. 0.68**	**Equ. 0.68**	**Equ. 0.69**
	Observed	1000000	**Equ. 0.68**	**Equ. 0.68**	**Equ. 0.68**	**Equ. 0.68**	**Equ. 0.68**	**Equ. 0.69**
GPX_4_19607	Modeled	10000	Fix. < 90 G	Fix. < 80 G	Fix. < 60 G	Fix. < 50 G	Fix. < 40 G	Fix. < 30 G
	Modeled	100000	Fix. < 80 G	Fix. < 70 G	Fix. < 50 G	Fix. < 40 G	Fix. < 30 G	Fix. < 30 G
	Modeled	1000000	Fix. < 70 G	Fix. < 60 G	Fix. < 50 G	Fix. < 40 G	Fix. < 30 G	Fix. < 30 G
	Observed	10000	Fix. < 90 G	Fix. < 80 G	Fix. < 50 G	Fix. < 50 G	Fix. < 40 G	Fix. < 40 G
	Observed	100000	Fix. < 70 G	Fix. < 70 G	Fix. < 50 G	Fix. < 40 G	Fix. < 40 G	Fix. < 30 G
	Observed	1000000	Fix. < 70 G	Fix. < 60 G	Fix. < 50 G	Fix. < 40 G	Fix. < 30 G	Fix. < 30 G
HSP_90A_15666	Modeled	10000	Fix. < 30 G	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G

	Modeled	100000	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G
	Modeled	1000000	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G
	Observed	10000	**Equ. 0.755**	**Equ. 0.755**	**Equ. 0.76**	**Equ. 0.78**	**Equ. 0.805**	**Equ. 0.85**
	Observed	100000	**Equ. 0.755**	**Equ. 0.755**	**Equ. 0.76**	**Equ. 0.78**	**Equ. 0.805**	**Equ. 0.85**
	Observed	1000000	**Equ. 0.755**	**Equ. 0.755**	**Equ. 0.76**	**Equ. 0.78**	**Equ. 0.805**	**Equ. 0.85**
MDH_1393	Modeled	10000	**Equ. 0.375**	**Equ. 0.365**	**Equ. 0.35**	**Equ. 0.33**	**Equ. 0.305**	**Equ. 0.28**
	Modeled	100000	**Equ. 0.375**	**Equ. 0.365**	**Equ. 0.35**	**Equ. 0.33**	**Equ. 0.305**	**Equ. 0.28**
	Modeled	1000000	**Equ. 0.375**	**Equ. 0.365**	**Equ. 0.35**	**Equ. 0.33**	**Equ. 0.305**	**Equ. 0.28**
	Observed	10000	**Equ. 0.37**	**Equ. 0.36**	**Equ. 0.345**	**Equ. 0.33**	**Equ. 0.31**	**Equ. 0.305**
	Observed	100000	**Equ. 0.37**	**Equ. 0.36**	**Equ. 0.345**	**Equ. 0.33**	**Equ. 0.31**	**Equ. 0.305**
	Observed	1000000	**Equ. 0.37**	**Equ. 0.36**	**Equ. 0.345**	**Equ. 0.33**	**Equ. 0.31**	**Equ. 0.305**
NRAP_1541	Modeled	10000	Fix. < 50 G	Fix. < 60 G	Fix. < 60 G	Fix. < 70 G	Fix. < 100 G	Fix. < 120 G
	Modeled	100000	Fix. < 50 G	Fix. < 50 G	Fix. < 60 G	Fix. < 70 G	Fix. < 90 G	Fix. < 110 G
	Modeled	1000000	Fix. < 50 G	Fix. < 50 G	Fix. < 60 G	Fix. < 70 G	Fix. < 80 G	Fix. < 110 G
	Observed	10000	Fix. < 60 G	Fix. < 70 G	Fix. < 80 G	Fix. < 100 G	Fix. < 90 G	Fix. < 60 G

	Observed	100000	Fix. < 60 G	Fix. < 60 G	Fix. < 70 G	Fix. < 90 G	Fix. < 80 G	Fix. < 60 G
	Observed	1000000	Fix. < 60 G	Fix. < 60 G	Fix. < 70 G	Fix. < 80 G	Fix. < 80 G	Fix. < 60 G
PRP_40_16504	Modeled	10000	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G
	Modeled	100000	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G
	Modeled	1000000	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G	Fix. < 20 G
	Observed	10000	**Equ. 0.92**	**Equ. 0.93**	**Equ. 0.935**	**Equ. 0.945**	**Equ. 0.955**	**Equ. 0.975**
	Observed	100000	**Equ. 0.92**	**Equ. 0.93**	**Equ. 0.935**	**Equ. 0.945**	**Equ. 0.955**	**Equ. 0.975**
	Observed	1000000	**Equ. 0.92**	**Equ. 0.93**	**Equ. 0.935**	**Equ. 0.945**	**Equ. 0.955**	**Equ. 0.975**
UGP_2_2128	Modeled	10000	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G
	Modeled	100000	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G
	Modeled	1000000	Fix. < 20 G	Fix. < 20 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G
	Observed	10000	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 20 G
	Observed	100000	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 20 G	Fix. < 20 G
	Observed	1000000	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 30 G	Fix. < 20 G	Fix. < 20 G

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Atlantic States Marine Fisheries Commission
Habitat Committee

Whitepaper on Habitat Bottlenecks and Fisheries Management

October 2015

Introduction

There is little dispute among fishermen, scientists and fishery managers that the amount, quality, and availability of habitats utilized by diadromous, estuarine, and marine species is a critical determinant of a fish stock's productivity and resilience. However, despite the widespread recognition, conservation of fish habitat remains one of the biggest challenges in fisheries management. There are at least three important reasons for this.

First, patterns (seasonal and temporal) of habitat use by a given species typically vary considerably both within and among life stages. Many species exhibit strong dependence on one or a small number of habitats, but many also show an ability to utilize different habitats at a given life stage in response to prey availability, density, or other factors. Habitat sections of most FMPs illustrate the diversity and complexity of habitat use.

Second, quantifying the relationship between habitat metrics (i.e., % cover, patchiness, density of structural features, etc.) and stock productivity is difficult for most species[1]. This means that decision-making often cannot be informed by estimates of an X% reduction in potential yield of a given species if Y acres of habitat are lost or degraded due to a proposed action (e.g., marina development, offshore energy facility, dredging, destructive fishing practice, etc.), or, conversely, that yield will increase due to habitat recovery through protection or restoration. The synergy of multiple impacts which degrade or improve habitat quality very often result in nonlinear or indirect responses in species' productivity.

Third, the range of impacts that affect habitat is broad, and fall under the purview of multiple agencies, not solely those responsible for harvest management. This creates a complex, and generally disconnected, governance structure that would likely have limited effectiveness even with a stronger and clearer scientific foundation.

In response to these challenges, the Atlantic States Marine Fisheries Commission (ASMFC) Habitat Committee has been working with the concept of *habitat bottlenecks* as a means of focusing both research and management on those areas likely to yield the greatest returns.

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[1] An important exception is the generally strong relationship between abundance of anadromous species and accessible river miles.

Definition

A Habitat Committee work group developed a proposed definition, which was modified slightly by the full Committee at its April 2013 meeting. The current working definition is as follows:

> *A habitat bottleneck is defined as a constraint on a species' ability to survive, reproduce, or recruit to the next life stage that results from reductions in available habitat extent and/or capacity and reduces the effectiveness of traditional fisheries management options to control mortality and spawning stock biomass.*

In other words, the concept of a habitat bottleneck is not meant to capture situations wherein the stock's response to changes in habitat conditions is gradual, incremental, or linear. Rather, a habitat bottleneck is a situation in which the response is sharp and pronounced, to a degree that it overwhelms the effectiveness of harvest control measures and creates excessive deviation from the constant or bounded conditions assumed by stock assessment models. Figure 1 illustrates potential relationships between habitat metrics and ecological responses in which a threshold exists at which the response is sharper and more sudden. Such thresholds are points at which habitat bottlenecks are likely to be created.

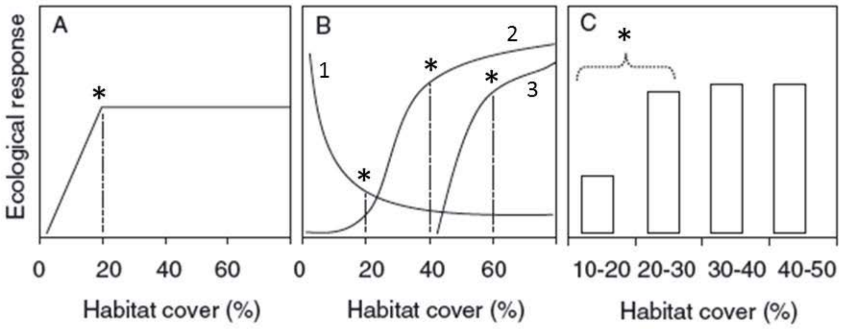

Fig 1. Possible functional relationships between habitat metrics and ecological response variables, such as key demographic rates (growth, mortality, recruitment). Asterisks mark thresholds at which a habitat bottleneck might be created. A and C represent situations in which the response variable is constant, or at least variable within bounds, over a wide range of habitat conditions, but then changes markedly past the threshold. B represents situations where there is an ecological response to habitat across all values, but the rate of change increases or decreases markedly at the threshold. Curve 1 in B represents a response variable that is inversely related to habitat, such as mortality rate. Curve 3 represents a response variable that is strongly tied to habitat, and for which the bottleneck is created when the habitat metric is still seemingly high. An example might be demographic rates during the juvenile stage when individuals are strongly dependent upon nursery habitat for shelter and feeding. (modified from Swift and Hannon 2010).

This is not to say that more gradual or linear changes are not important. If, for example, a 5% reduction in some key habitat metric causes a 5% reduction in growth rate[2] for a given species, but

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[2] Although the definition proposed by the Habitat Committee does not explicitly include growth, among other important attributes (e.g., condition, behavior, etc.), those attributes affect survival, reproduction and recruitment, and therefore are implicit within the definition.

the stock assessment model does not account for that change, then the actual dynamics will deviate from those predicted by the model and management will seem to underperform. However, such a deviation is modest and within the range of expected error and uncertainty, and a response to harvest controls would still likely be observed (assuming other errors and uncertainties are not excessive). A habitat bottleneck is the point at which the deviations from model assumptions are no longer minor, and prevent expected responses to management.

It is important to note that incremental or linear responses to changes in habitat metrics can lead to a habitat bottleneck if the changes are continuous, directional, and not detected scientifically or incorporated into management. For example, a 5% reduction in growth rate due a modest change in habitat might have tolerable effects, but if the reduction grew to 30% through sustained declines in habitat, then the deviation would be excessive even if the change did not look like crossing a threshold (per Figure 1). At that stage, it would also represent a habitat bottleneck. One response might be to take no action on the habitat conditions in the water, and instead adjust the assessment model to better account for the new reality (i.e., lower productivity and recoverability regime). Or, action could be taken to remove the bottleneck and restore the previous productivity regime.

Importantly, habitat bottlenecks can come and go for a given stock in response to changes in habitat condition as well as stock size. Habitat is a key determinant of carrying capacity, and adverse impacts on habitat can lower carrying capacity. However, if the stock size is below even the reduced carrying capacity, then a bottleneck will not be evident and the stock should respond to harvest controls. Once the stock approaches the new lower carrying capacity created by changes in habitat conditions, then the bottleneck will become evident as the stock no longer responds as expected under the (incorrectly) assumed conditions.

Categories of Habitat Bottlenecks

Habitat bottlenecks can be categorized as environmental and physical. The distinction differentiates bottlenecks that can be addressed by habitat management measures, such as barriers and direct human activities (physical), from those that cannot be as easily controlled, such as temperature changes (environmental).

Environmental Habitat Bottlenecks

Some species may require specific ranges of environmental conditions such as temperature, pH, salinity, and dissolved oxygen during crucial life stages. Accelerated shifts in these environmental conditions may create habitat bottlenecks that are more challenging, if not impossible, to address with management measures. However, these environmental habitat bottlenecks should be factored into management measures as risks that may compromise a species' ability to rebuild or recruit to the population.

Examples of environmental habitat bottlenecks are temperature shifts for American lobster, oxygen levels for summer and winter flounders, spawning beach availability for horseshoe crab, and access to spawning areas for Atlantic sturgeon (see case studies below). Management measures which accommodate these risks include fishery closures during high temperature months, restrictive size limits to preserve genetically adapting survivors, harvest and quota transfers among jurisdictions, and precautionary trip/bag limits which account for higher mortality rates for vulnerable size classes.

Physical Habitat Bottlenecks

Habitat bottlenecks related to substrate, depth, turbidity, light penetration, water flow, and other physical conditions can be more feasible to address with habitat management measures and activities than the environmental bottlenecks. For example, the New England Fishery Management Council (NEFMC) is proposing to update the winter flounder EFH to better protect spawning grounds from dredging activities in its Draft Omnibus Habitat Amendment 2.

Case studies

As the Habitat Committee continues to refine the habitat bottleneck concept, we are exploring the utility of new data presented in updates to the Habitat Sections of different FMPs. The following examples illustrate how the concept is being considered and applied in the management of different stocks.

American Lobster

The updated Habitat Section draft of the American lobster FMP identifies two observed potential habitat bottlenecks for the species. Neither relate to structural habitat attributes (i.e., benthic features such as vegetation, sessile fauna or sediment type). Instead, both relate to water quality attributes and the physiological and behavioral responses by individuals within the stock.

Habitat Bottlenecks

The first bottleneck is a temperature threshold effect that was most evident in Long Island Sound at the time of the massive 1999 lobster die-off. Fall water temperatures increased rapidly that year causing thermal stress and mortality, and also caused lobster to aggregate in deeper thermal refuges. These stressed animals were less resistant to several chronic diseases. The result was mortality on the order of 90% or more that year. In subsequent years, continued high temperatures during the fall season caused further physiological stress, overwhelming any expected benefits of fisheries management. Research has demonstrated that lobsters show a distinct and abrupt response to water temperatures above 20°C (Crossin et al. 1998) which field studies have shown can double observed mortality rates (Figure 2), making elevated temperature a true bottleneck for this species.

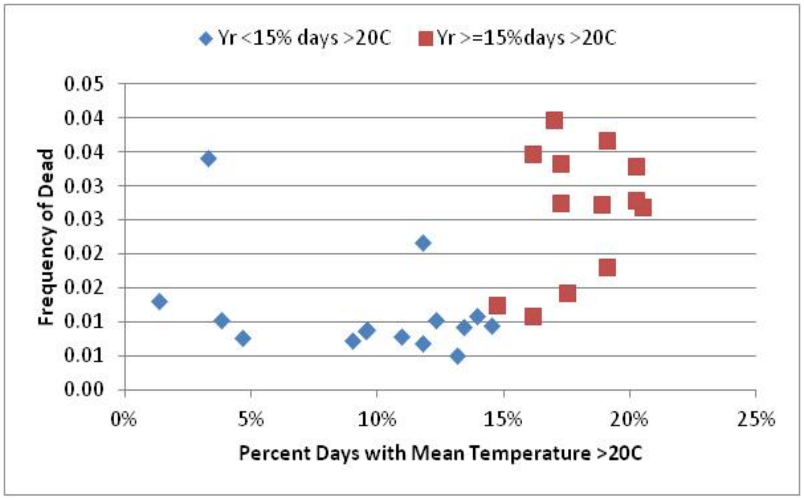

Fig 2. Relationship between the observed annual frequency of dead lobsters in research traps versus the percent of days that year with a mean bottom water temperature above 20ºC. (Data provided by Millstone Environmental Laboratory, Dominion Nuclear Resources)

The second bottleneck is also linked to temperature, and involved the reduction and contraction of suitable thermal habitats in several locations off southern New England (Figure 3). This has caused lobster to be absent from traditional nearshore fishing grounds, reducing availability to the fleet and subsequent yield. There is some evidence that displacement of egg-bearing females into deeper water has resulted in newly hatched planktonic larvae being carried on currents out to open ocean waters where their survival rate is diminished. It is not clear whether and to what extent the stock has experienced a decrease in productivity as a result of these increases in temperature, or whether the change has primarily been one of distribution. Regardless, the effect is similar in that the fishery does not perform as expected.

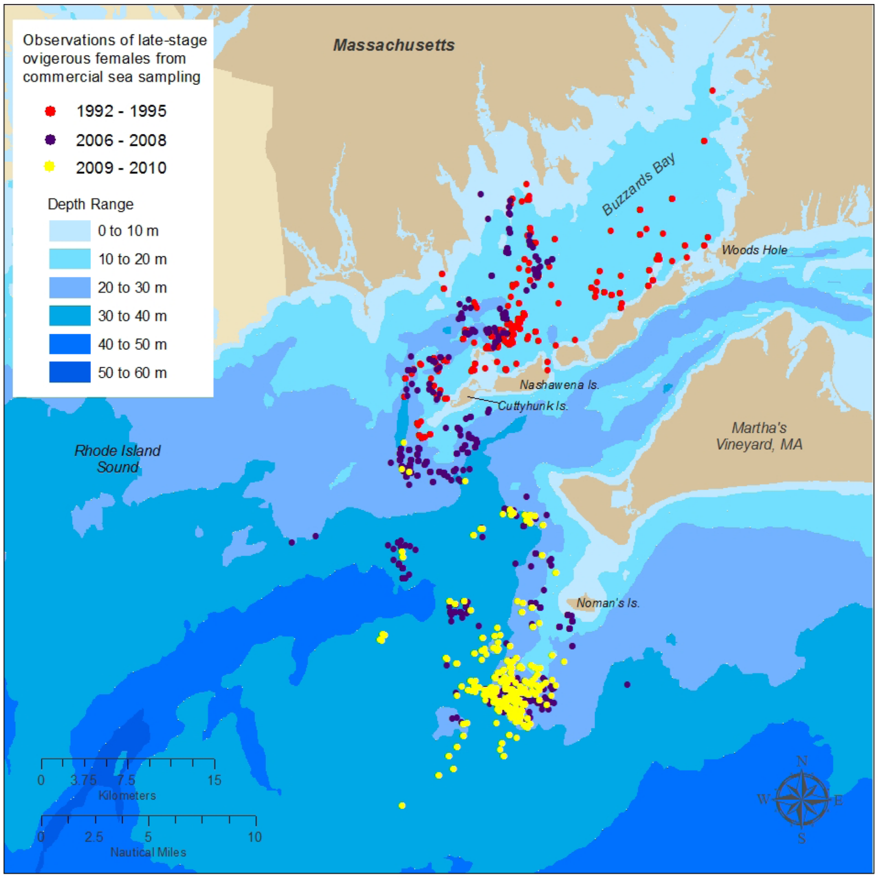

Fig 3. Map of distribution shift in late-stage egg bearing female lobsters in southern New England that has been related to changes in temperature. From: MA DMF 2011

Summer and Winter Flounder

Habitat Requirements

These two specialized flatfish rely on shallow estuaries for their nursery grounds, which contribute substantially to successful recruitment of juveniles to the adult population (Beck et al. 2001). A bottleneck, as defined above, can often develop when these nursery areas experience chronic seasonal hypoxia due to excessive nutrient loading and eutrophication. Laboratory studies of juveniles of these two species (Stierhoff et al. 2006) show that growth of winter flounder at 20°C was reduced by ~50% at both 3.5 and 5.0 mg O_2 l^{-1} (compared to growth at normoxia [7.0 mg O_2 l^{-1}]), and growth was completely halted at 2.0 mg O_2 l^{-1}. Similarly, summer flounder growth was reduced by ~25% at 3.5 mg O_2 l^{-1} and by 50 to 60% at 2.0 mg O_2 l^{-1}. Importantly, there was no evidence of growth acclimation for either species after 7—14 d exposure to hypoxia, and these levels of hypoxia commonly persist in many coastal estuaries. The distinct drop in growth at DO levels below 3.5 mg O_2 l^{-1} was attributed to reduced feeding rates under hypoxic conditions. These significant reductions in juvenile growth rates, at sizes and ages below those usually modeled for fishery management, can translate into significant reductions in the ultimate production of the entire population (Eby et al. 2005), resulting in overly optimistic model predictions under reduced fishing mortality on the adult stock.

Horseshoe Crab

Habitat Requirements

Horseshoe crabs are evolutionary survivors that have remained relatively unchanged physically for over 350 million years (Figure 4). Of four species worldwide, the one species (*Limulus polyphemus*) in North American waters is the most abundant and ranges on the Atlantic coast from Maine to the Yucatan Peninsula. Adults remain in larger estuaries or migrate to the continental shelf during the winter months, returning inshore in spring to beach areas to spawn. Spawning usually coincides with a high tide during full and new moon phases. Eggs are laid in clusters of a few thousand in buried nest sites along the beach, totaling as many as 90,000 eggs per female per year spread over several spawning events. Such a large number of eggs play an important ecological role in the food web for multiple species of migrating shorebirds specialized in digging them out of the sand. Juvenile crabs hatch from the beach environment and spend their first two years in near shore nursery grounds. Horseshoe crabs molt at least six times in their first year of life and about 17 times until they become sexually mature at ages 9—12 years. The average life span of adults reaching maturity has been estimated at 20 years.

Fig 4. Horseshoe crabs on a beach in Fairfield, Connecticut. Photo credit: Penny Howell, CT Department of Energy and Environmental Protection.

Habitat Bottlenecks

The most important structural habitat attribute dictating stock status, spawning success, and recruitment is the ready availability of high quality spawning beaches. Despite their primitive physiology, these animals have developed sensory organs that allow them to perceive and chose spawning beaches that promote successful egg development and juvenile survival. These beaches are sloped such that the tidal prism creates an intertidal band with variable inundation and they are thereby protected from strong winds and surf which disrupts the mating process. High quality beaches are composed of a sand/pebble mixture optimal for incubating horseshoe crab eggs in terms of aeration and moisture. From Massachusetts to Delaware, productive spawning beaches are typically coarse-grained and well-drained to maintain adequate oxygen levels; productive southern spawning beaches are typically fine-grained and poorly drained where desiccation is a larger mortality factor (Brockmann 2003).

Schaller et al. (2010) concluded that most horseshoe crabs in the Great Bay Estuary in New Hampshire tended to spawn on beaches nearer to where they overwintered. Landi et al. (2014) also found that the probability of a beach segment in Connecticut falling into a higher use category increased with increasing slope, decreasing wave exposure, and decreasing distance from offshore congregations of overwintering adults. Therefore the distribution of high quality spawning beaches, which are exposed to only minimal human disturbance, also presents a bottleneck to reproductive success for this species. Disruption to beaches during the spawning season should be minimized by both reducing direct (e.g. harassment of horseshoe crabs, eggs, or predatory birds, Figure 5) and indirect (e.g. bulkheads and riprap) human impacts. In addition to tightly managing horseshoe crab removals, an effective management strategy should recognize and accommodate linkages among offshore overwintering grounds, high quality spawning beaches, and juvenile nursery areas, maintaining priority beach habitat long term. Seasonal area closures designed with these linkages in mind would optimize horseshoe crab reproduction and recruitment, while also promoting their contribution to the regional food web. Restrictions on development and regulations on shoreline hardening, as well as enforcement of existing and future regulations are recommended. This includes the appropriate use of living shoreline designs to maintain beach slope and energy characteristics in the face of sea level rise.

Fig 5. Predation on horseshoe crabs by predatory birds is common on beaches. Photo credit: Penny Howell, CT Department of Energy and Environmental Protection.

Atlantic Sturgeon

The Atlantic Sturgeon is a highly migratory anadromous fish, and each estuary analyzed hosts one or more genetically distinct populations (Grunwald et al., 2007; Balazik and Musick 2015). Historically, Atlantic Sturgeon were documented in 38 rivers ranging from Labrador to the St. Johns River in Florida. Thirty-five of these historical rivers currently have Atlantic Surgeon present, but only 21 (possibly only as few as 19) have one or more extant breeding populations (ASSRT, 2007, Table 1, p. 140; Hager et al. 2014; Balazik and Musick 2015).

Physical Bottlenecks

Dams – Spawning and recruitment appears to be most successful in rivers without dams blocking access to historical spawning habitat (hard surfaces such as cobble). These include the Hudson (NY), James (VA), and Altamaha (GA) rivers. The Cape Fear (NC), Santee-Cooper (SC), and St. Johns (FL) river systems have lost greater than 62% of the habitat historically used for spawning and development; only 42% of the historical habitat is available in the Merrimack River (MA, ASSRT, 2007). Barriers to spawning areas can cause females to resorb eggs and not spawn. Fish passage measures beneficial (i.e. safe, timely, and effective) to Atlantic Sturgeon have had limited success but alternate designs are being developed (Schilt 2007; Kynard et al. 2008; Katopodis and Williams 2012). In addition to being a physical barrier, dams can alter or degrade sturgeon habitat downstream by reducing water quality and availability of spawning habitat through temperature, flow, or oxygen content changes. Water flows (both seasonal flow timing and natural rate of flow delivery affect habitat suitability), water temperatures, and concentrations of dissolved oxygen (DO) are all affected by peaking operations from hydroelectric facilities.

Dredging – Removal and displacement of sediment modifies the quality and availability of Atlantic Sturgeon habitat, mainly through sedimentation. It can alter overall water quality (salinity and dissolved oxygen) greatly reducing the value of foraging and nursery habitat. Dredging operations have also been documented capturing 14 Atlantic Sturgeon from 1990—2005 (ASSRT, 2007).

Environmental Bottlenecks

Secor and Gunderson (1998) noted a correlation between low abundance of Atlantic Sturgeon and decreasing water quality caused by increased nutrient loading and increased spatial and temporal frequency of hypoxic conditions. Frequent occurrences of low DO concentrations in combination with high summer water temperatures are a particular concern. A bioenergetics and survival model for Chesapeake Bay demonstrated that a combination of low DO concentration, water temperature, and salinity restricts available Atlantic Sturgeon habitat to 0—32.5% of the Bay's modeled surface area during the summer (Niklitschek and Secor, 2005). Sturgeon are more sensitive to low DO concentrations (<5 mg l^{-1}) than other fish species (Niklitschek and Secor, 2009a, 2009b) and experience sublethal to lethal effects as DO concentration drops and temperatures rise. Summer mortality has been observed at <3.3 mg l^{-1} and at 26°C.

Final Thoughts

Over the course of writing this paper, the Habitat Committee discussed the role that humans play in the marine environment, both indirectly and directly. Arguably, humans have had some influence, either directly (e.g. shoreline hardening) or indirectly (e.g. through CO_2 emissions, thus increasing water temperature), on each habitat bottleneck addressed above. Because of the complex interactions among humans, habitat, and other environmental factors (both biotic and abiotic), it was at times difficult to focus on the effects of habitat bottlenecks without acknowledging other potential influences on spawning stock biomass. We ask that the reader please keep the intended scope of this paper in mind, as it is not a comprehensive examination of all of the variables that can impact fisheries, whether natural or anthropogenic.

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HABITAT CONSIDERATIONS

Habitat Important to the Stocks

Description of the Habitat

Pandalus borealis, commonly known as northern or pink shrimp, has a discontinuous distribution throughout the North Atlantic, North Pacific, and Arctic Oceans. In the Gulf of Maine, northern shrimp populations comprise a single stock (Clark and Anthony 1981), which is concentrated in the southwestern region of the Gulf (Haynes and Wigley 1969; Clark et al 1999, see Figure 3). Water temperature, depth, and substrate type have all been cited as important factors governing shrimp distribution in the Gulf of Maine (Haynes and Wigley 1969; Apollonio et al. 1986; Clark et al. 1999; Table 6).

Temperature

Ocean temperatures have an important influence on northern shrimp in the Gulf of Maine (Apollonio et al. 1986; Richards et al. 1996; Richards et al. 2012). Adult northern shrimp have been reported to live in waters from –1.6^{0}C (Gorbunow 1934; Ingraham 1981) up to around 12^{0}C (Bjork 1913; Allen 1959), while larvae can tolerate temperatures up to at least 14^0 C (Poulson 1946); however, the most common temperature range for this species is 0-5^0 C (Shumway et al 1985). The Gulf of Maine marks the southern-most extent of this species' range, and the amount of available habitat occupied by this species is limited to the western region of the Gulf (west of 68^0 W) where bottom topography and oceanographic conditions create submarine basins protected from seasonal warming by thermal stratification. The deep basins act as cold water refuges for adult shrimp populations. In northeastern regions of the Gulf, large shrimp populations do not persist because bottom waters are not protected from seasonal warming due to continual mixing from intense tidal currents nearer the Bay of Fundy.

Seasonal water temperatures in many areas regularly exceed the upper physiological limit for northern shrimp. During the warm period of the 1950s, northern shrimp catches declined to zero despite continued fishing effort (Dow 1964), suggesting a population collapse. Spring ocean temperatures during the larval period are particularly important for recruitment, with cooler temperatures favoring higher recruitment (Richards et al. 2012). Spawner abundance also influences recruitment strength, with more recruits resulting from higher spawner abundance (Richards et al. 2012).

Sea surface temperature (SST) has been measured daily since 1906 at Boothbay Harbor, Maine, near the center of the inshore nursery areas for northern shrimp. Annual average SST at Boothbay increased from an average of 7.9 °C during 1906-1948 to an average of 10.4 °C during 2000-2013 (Figure 17). SST has exceeded the 1953 high point three times in the past decade, and 2012 was the warmest year in the 109 years of record. Similar trends have been seen during Feb-March, Figure 17), a critical time for determining recruitment strength. Feb-Mar SST was very high in 2012, but declined in 2013 and again in 2014. Spring temperature anomalies (temperature changes measured relative to a standard time period) in offshore shrimp habitat areas were the highest on record during 2012 (surface temperature) and 2011-2012 (bottom temperature) (NEFSC trawl survey data, 1968-2012; Figure 17). Temperature anomalies remained high in

2013, but were cooler in 2014. The spring bottom temperature anomaly in 2014 was near the long term average.

Depth

In the Gulf of Maine, northern shrimp are most frequently found from about 10 m to over 300 m (Haynes and Wigley 1969), with juveniles and immature males occupying shallower, inshore waters and mature males and females occupying cooler, deeper offshore waters for most of the year (Apollonio and Dunton 1969; Haynes and Wigley 1969, Apollonio et al 1986). During the summer months, adult shrimp inhabit water from 93-183 m (Clark et al. 1999); ovigerous female shrimp are found in shallower near-shore waters during the late winter and spring (Clark et al. 1999) when their eggs are hatching.

Substrate

Within its preferred temperature range, northern shrimp most commonly inhabit organic-rich, mud bottoms or near-bottom waters (Wollebaek 1908; Hjort and Rund 1938; Horsted and Smidt 1956; Warren and Sheldon 1968), where they prey on benthic invertebrates; however, the shrimp is not limited to this habitat and has been observed on rocky substrate (Berkeley 1930; Balsiger 1981). Shrimp distribution in relation to substrate type determined by spring, summer (Figure 4), and autumn (Figure 3) fisheries independent trawl surveys, clearly show northern shrimp primarily occupy areas with fine sediments (sand, silt, and clay). Shrimp are often associated with biotic or abiotic structures such as cerianthid anemone tubes (Langton and Uzmann 1989) and occasional boulders (Dan Schick, Maine Department of Marine Resources, pers.comm.) in these fine sediment habitats.

Other Environmental and Life History Features Governing Northern Shrimp Distribution

Northern shrimp occupy a variety of habitats during their complex life history. Like all members of the family Pandalidae, northern shrimp are protandric hermaphrodites, developing first into functional males, and later undergoing a transformation into females. Distribution and migratory patterns of this species change with age, (and in the case of females, with season), causing habitat preference to shift with different life history stages.

In addition to age and seasonally correlated horizontal migrations, northern shrimp exhibit diel vertical migration in the water column. There is strong evidence that northern shrimp leave the bottom at night and distribute themselves throughout the water column, presumably to feed (Wollebaek 1903; Hjort and Ruud 1938; Barr 1970). Gut contents of this species have been shown to include planktonic crustaceans (Horsted and Smidt 1956). In thermally stratified waters, northern shrimp will migrate up to, but not penetrate the thermocline (Apollonio and Dunton 1969). After spending the night dispersed in the water column, shrimp return to the bottom around dawn where they feed on a wide variety of soft bottom benthic invertebrates (Wienberg 1981).

As a stenohaline species, northern shrimp are restricted to water with moderately high salinities (Allen 1959). Their occurrence has been noted in waters with salinities ranging from a low of 23.4 to 35.7 (Shumway et al. 1985)

Spawning Habitat

In the Gulf of Maine, northern shrimp spawn in offshore waters beginning in late summer months (Haynes and Wigley 1969). The precise locations of spawning grounds are not well documented but it is reasonable to conclude that spawning occurs in offshore summertime population centers in deep mud basins in the southwestern Gulf (Haynes and Wigley 1969; Apollonio et al 1986). Ovigerous females remain in cold, stratified bottom waters offshore through the fall until near-shore waters have cooled, at which time they begin an inshore migration to release their eggs (Haynes and Wigley 1969; Apollonio et al. 1986). Inshore migration routes followed by the northern shrimp are not well known, but due to their well established preference for organic-rich mud bottoms, it has been suggested that female shrimp probably move inshore over muddy substrates and are eventually concentrated in, but not limited to, mud-bottom channels near-shore (Dan Schick, pers.comm.).

Eggs & Larval Habitat

After their arrival in nearshore waters, the female shrimp's mature eggs begin to hatch. Hatching occurs as early as February and lasts through April (Haynes and Wigley 1969; Stickney and Perkins 1979) after which time female shrimp return to offshore waters in the western Gulf. The pelagic larvae are planktotrophic, feeding primarily on diatoms and zooplankton (Stickney 1980). A survey of larval shrimp distribution conducted by Apollonio and Dunton (1969) showed that larvae were abundant almost exclusively within 10 miles of shore. Little is known about the vertical distribution of larval shrimp within the water column. While in the plankton, northern shrimp pass through six larval stages (Berkeley 1930; Stickney and Perkins 1979) before completing a final metamorphosis to a juvenile stage and settling to the bottom in near-shore waters after about 30 to 60 days (Rinaldo 1981). It is important to note that time of egg release, larval hatch, and larval development rate are temperature related, with colder water temperatures resulting in slower developmental progress (Allen 1959, Richards 2012). Thus, the timing of egg release, hatch, and length of pelagic larval stages may vary slightly from year to year as a result of water temperature fluctuations in the Gulf of Maine (Koeller et al 2009). In general, the start of the hatch period has become earlier as temperatures have increased, with the hatch in recent years beginning more than a month earlier than it did previous to 2000 (10% line in Figure 16). The midpoint of the hatch period has not changed as much as the start of the hatch (50% line in Figure 16). With the cooler temperatures in 2014, the hatch began later and reached its midpoint later than in other recent years (Figure 17).

Juvenile Habitat

By late summer, nearly all newly metamorphosed juveniles have settled to the bottom in relatively shallow, near-shore areas usually within 10 miles of the coast (Apollonio and Dunton 1969). These immature shrimp remain inshore for up to 20 months as they grow and develop into mature males (Apollonio and Dunton 1969). Relatively little is known about the distribution and habitat requirements of this life history stage. After as little as a year, some juveniles begin to migrate offshore to deeper waters. Eventually, all juveniles will migrate offshore where they will complete their development into mature males around the age of 2 (29-30 months old) (Apollonio and Dunton 1969; Haynes and Wigley 1969). Their migration routes and factors triggering migration to deep, offshore, muddy basins are not well known.

Adult Habitat & Distribution in the Gulf of Maine

Adult shrimp distributions appear to be governed by seasonal changes in water temperature.

During the summer months, adult shrimp are confined to cold waters (4-6^{0}C) found only in the deeper basins (92-183 m) in the southwestern Gulf of Maine. Female shrimp are found in abundance in near-shore waters only during the late winter and spring when coastal waters are coldest (Clark et al. 1999). Within their preferred temperature range, northern shrimp occur mainly on mud bottom habitats (Clark et al. 1999) where the organic matter content of the sediment is high (Haynes and Wigley 1969). Bigelow and Schroeder (1939) and Wigley (1960) found a direct correlation between shrimp abundance and sediment organic matter content. Apollonio et al. (1986) argued that temperature is the most important factor driving the distributional patterns of shrimp in the Gulf. They suggest that correlations between shrimp abundance and fine sediments with high organic matter content may be purely coincidental because deep, quiescent environments in the Gulf of Maine are characterized by both cold, unmixed water and accumulation of fine sediments.

Mud bottom habitats which support large populations of shrimp include: Jeffrey's basin (Apollonio and Dunton 1969), Cashes basin, Scantum basin (Dan Schick, Maine Department of Marine Resources, pers.comm.) and the region southeast of Mount Desert Island, Maine (Haynes and Wigley 1969). There are small populations in deep, cold water pockets in Penobscot Bay (Dan Schick, pers.comm.) and in the Sheepscot River (Les Watling, University of Maine, pers. comm.).

During the winter and spring, when nearshore and offshore surface waters have cooled to the temperature range of shrimp, the amount of habitat available to adult shrimp increases. A wintertime fishery for northern shrimp extends as far south as the outer arm of Cape Cod, reaches as far north as Jonesport, Maine (Dan Schick, pers.comm.)

Identification and Distribution of Habitat Areas of Particular Concern

Nearshore waters (out to 10 miles)

Nearshore waters provide habitat for the larval and juvenile stages of northern shrimp. The survival of these early life-history stages is essential to the success of the species. Nearshore habitats are impacted by a myriad of anthropogenic activities including coastal development, pollutant run-off, harbor dredging, etc. The effects of these and other human activities on habitat quality for larval and juvenile northern shrimp are not known at this time.

Deep, muddy basins in the southern region of the Gulf of Maine

Deep, muddy basins in the southwestern region of the Gulf of Maine act as cold water refuges for adult shrimp during periods when most water in the Gulf reaches temperatures that are lethal to this arctic/sub-arctic species. Changes in the oceanographic conditions due to the North Atlantic Oscillation, climate change, or other natural factors may cause warm water to intrude into some of the deep basins in the southwestern Gulf rendering this habitat unsuitable for shrimp and possibly resulting extirpation of local populations.

In addition to naturally occurring environmental changes, some deep, muddy bottom habitats are impacted by the use of mobile fishing gear to harvest groundfish (e.g.-trawls). Groundfish gear generally has a longer sweep and is towed much faster over the bottom. The small mesh in the shrimp gear creates more drag than a groundfish net and can't be towed as fast for the same size net. Also, groundfish gear generally has a larger diameter roller/rockhopper frame.

The effects of this type of fishing gear on habitat quality for shrimp are not known at this time. The use of mobile fishing gear has been shown to reduce structural complexity of bottom habitats (Auster et al. 1996). Such an effect could potentially reduce the survival of adult shrimp, which seem to utilize biotic and abiotic structures on mud bottoms, possibly to avoid predation.

Simpson and Watling (2006) suggested that seasonal trawling with shrimp gear on mud bottoms produced at least short-term changes (<3 months) in macrofaunal community structure, but did not appear to result in long-term cumulative changes.

Present Conditions of Habitats and Habitat Areas of Particular Concern

Near-shore waters

Near-shore habitats are impacted by a myriad of anthropogenic activities including coastal development, pollutant run-off, harbor dredging, etc. At this time, the inshore habitats occupied by larval and juvenile shrimp have not been mapped, and therefore it is not possible to identify the condition of, or specific anthropogenic threats to these habitats.

Deep, muddy basins

The effects of temperature on shrimp abundance have long been a subject of study, however, more information is required before it is possible to predict the effect of large-scale climatic events (like the North Atlantic oscillation, or climate change) on the amount of suitable habitat available to adult shrimp.

Likewise, the effects of mobile fishing gear on bottom habitats have been a subject of study for over a decade; however, the long-term impacts of trawling on shrimp habitat in deep, muddy basins is not known at this time.

Temperature Considerations

While the manner by which temperature affects recruitment and abundance trends has not been precisely determined, record high sea surface temperatures during the early 1950s correlate with complete failure of the fishery from 1954-1957; and conversely, the cold temperature years of the early to mid-1960s appear to have been very favorable for recruitment, with rapid increases in abundance and record landings from 1969-1972. The collapse of the fishery during the 1970s was more problematic as it occurred during a period of warming temperatures, and high and increasing levels of fishing mortality rate; overfishing has been strongly implicated for the collapse. During the next two decades, significant recruitment events have coincided with normal to below normal spring sea surface temperature anomalies.

Given that this resource is at the southernmost extent of its Atlantic range, one would expect that temperature conditions would have a significant influence on long-term trends in abundance. Apollonio *et al*. (1986) concluded that this resource, because of its geographic location and its inherent susceptibility to environmental influences, would be inherently unstable. Dow (1977) found an inverse correlation between abundance and sea surface temperature (i.e. abundance is higher with lower sea surface temperatures) and has since been corroborated (Richards *et al*. 1996 and others). Koeller et al (2009) suggested that the winter inshore migration of egg-bearing females may be a behavioral adaptation to relatively warm (compared with other locations in their range) bottom water temperatures that delays egg development and brings hatching time closer to the time of spring bloom. This effect would be enhanced when temperatures of the well-mixed nearshore waters were colder, leading to the observed negative correlation between abundance and temperature. This stock appears to be one of the few for which previous relationships between environmental influences and abundance trends remained statistically significant when reexamined (Myers 1998).

Ecosystem Considerations

Recently, the ASMFC, NOAA Fisheries Service, and several Fishery Management Councils have begun incorporating Ecosystem-Based Fisheries Management (EBFM) strategies into their fishery management programs. In general, EBFM strategies are adaptive management approaches that are specific to a geographic region, account for environmental influences and uncertainties, and strive to balance diverse ecological, social, and economic objectives.

By developing EBFM strategies, the Commission and its partner agencies are attempting to move beyond the traditional focus on single-species dynamics by considering environmental and human influences on fish populations and their sustainable harvest (e.g. multispecies interactions, climate change, coastal development). EBFM strives to integrate ecological, social, and economic goals while recognizing humans as key components of the ecosystem. EBFM also engages a broad and diverse group of stakeholders in a collaborative process to define problems and find solutions providing mutual benefit.

Although an EBFM strategy has not been developed for northern shrimp, its distribution throughout the Gulf of Maine and importance to the marine food web make it a good candidate for consideration (e.g. Link and Idoine, 2009). Predator-prey interactions with several demersal finfish species (e.g., Atlantic cod, redfish) exist throughout the northern shrimp range (Worm and Myers 2003; Savenkoff et al. 2006). Given the data requirements necessary to incorporate multi-species interactions appropriately, it would be a challenge to use an EBFM for northern shrimp. However, the Commission's Multispecies Technical Committee, Northern Shrimp Technical Committee (NSTC) and the NEFMC continue to work on refining multi-species modeling approaches to be used in future assessments of managed species, including northern shrimp.

RECOMMENDATIONS

The NSTC bases its recommendations to the Section on its assessment of current stock status, the biology of the species, and the stated management goal of protecting and maintaining the stock at levels that will support a viable fishery on a sustainable resource (Amendment 2 to the FMP, ASMFC 2011).

Short-term commercial prospects for the 2015 fishing season are very poor given the record low index of exploitable biomass in 2014 and the relatively small size of females. Longer-term prospects are also poor due to the unprecedented low abundance of age 1.5 shrimp seen in the 2012 - 2013 summer surveys, which would be the main contributors to a 2016 fishery. The recruitment index increased marginally in 2014, but was still well below the stable period mean (1984-1993). These recruits (2013 year class) are not expected to reach exploitable size until 2017.

Long term trends in environmental conditions are not favorable for northern shrimp. This suggests a need to conserve spawners to help compensate for what may continue to be an unfavorable environment.

Given the depleted condition of the resource and poor prospects for the near future, the NSTC strongly recommends that the Section extend the moratorium on fishing through 2015.

HABITAT CONSERVATION AND RESTORATION

Preservation of Existing Habitat

Until the habitat requirements for larval, juvenile, and adult shrimp are understood and maps of essential habitat for these life history stages are developed it is not feasible to make recommendations or develop requirements to conserve the inshore habitats utilized by these life history stages. The New England Fishery Management Council is developing an Omnibus Habitat Amendment that will likely contain additional information on the status of northern shrimp habitat in the Gulf of Maine. This Section can be updated in a subsequent amendment or addendum based on available information.

Habitat Restoration, Improvement, and Enhancement

Until the habitat requirements for larval, juvenile, and adult shrimp are understood and maps of essential habitat for these life history stages are developed it is not feasible to make recommendations or develop requirements to conserve the inshore habitats utilized by these life history stages. The New England Fishery Management Council is developing an Omnibus Habitat Amendment that will likely contain additional information on the status of northern shrimp habitat in the Gulf of Maine. This Section can be updated in a subsequent amendment or addendum based on available information.

RESEARCH AND DATA NEEDS

Habitat

- Study specific habitat requirements for all life history stages.
- Develop habitat maps for all life history stages.
- Identify migration routes of immature males offshore, and ovigerous females inshore.
- Study the effects of large-scale climatic events (like the North Atlantic Oscillation) on the cold water refuges for shrimp in the Gulf of Maine.
- Determine the short and long-term effects of mobile fishing gear on shrimp habitat.
- Evaluate effects of habitat loss/degradation on northern shrimp.

Tautog Stock Assessment for Peer Review (Accepted for Management Use February 2015) + Addendum III (2002)

3.0 HABITAT DESCRIPTION (Pages 13- 14)

Tautog are attracted to some type of structured habitat in all post larval stages of their life cycle. These habitats include both natural and man-made structures, such as submerged vegetation, shellfish bed, rocks, pilings, accidental shipwrecks and artificial reefs (Olla et al, 1974; Briggs 1975; Briggs and O'Connor 1971; Orth and Heck 1980; Sogard and Able 1991; Dorf and Powell 1997; Steimle and Shaheen 1999).

Commented [LH1]: Missing citation in Stock Assessment

Juvenile tautog require shelter from predators and for feeding and are often found in shallow nearshore vegetated areas such as eelgrass beds or algae beds. A series of laboratory habitat choice experiments in Delaware indicated that YOY tautog showed greatest preference for *Ulva lactuca*-fouled rock structures, followed by *Ulva lactuca* alone, rock structure, and the least preferred habitat studied, *Zostera marina,* eel grass (Wong and Targett in preparation). No SCUBA observations of YOY recruitment were reported on coastal reef sites (located greater than 10 km from shore). However, limited observations of YOY were noted on estuarine reef structures, (rocky reefs with and without macroalgae present). Other studied have found that newly settled individuals are reported to prefer areas less than one meter deep (Sogard et al 1992, Dorf and Powell 1997), but move out to deeper water as they grow. Juvenile tautog have been shown to have size specific preference when choosing a shelter (Dixon 1994) and appear to have a strong affinity to their home site, rarely venturing more than a few meters away (Olla et al. 1974). During the winter, juveniles are believed to remain inshore at perennial sites and disperse during the spring (Stolgitis 1970; Olla et al. 1979). A study examining the habitat-related differences in growth rates in young of the year in their northern range found that growth rates varied and were most likely dependent on a variety of biotic and abiotic factors (Phelan et. al, 2000). From this study it would be difficult to evaluate the effect of habitat quality on growth due to the variability and limited geographic scope.

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Adult tautog prefer highly structured habitat, including rock piles, shipwrecks and artificial reefs which provide food and sheltering sites. Tautog exhibit diurnal activity and enter a torpid state at night during which they seek refuge in some type of structure. Soon after morning twilight, tautog have been observed leaving their night time shelter to feed throughout the day (Olla et al. 1974; 1975). From April through June, fish were collected in spawning condition from inside the Chesapeake Bay out to 35 miles offshore (depth = 120 feet). It appears that tautog spawn during the daylight ebb tidal current (White, 1996).

The overwintering habitat of adult tautog is poorly understood. When water temperatures fall between 5-8°C, tautog enter a torpid state and hide in some type of structured habitat (Cooper 1966, Olla et al 1974, 1979). A study on the seasonal occurrence of tautog in the lower Chesapeake Bay indicates that most fish tagged and released in inshore waters remained inshore for the winter rather than moving offshore (Arendt, Lucy, and Munroe, 2001). Tautog observed by other researchers in NY, RI, and MA moved offshore during winter months.

Commented [LH3]: Was not cited in Addendum; could use a citation.

Little is known about habitat needs critical to recruitment levels, but given the small percentage of structured habitat, relative to the overall marine habitats along the Northern Atlantic coast, one could safely assume that tautog range is bounded to some degree by available habitat. This may be especially true in the region south of Long Island, NY where relatively little natural rock habitat exists compared to the structure rich northeastern states (Flint 1971).

8.0 RESEARCH RECOMMENDATIONS (Pages 73-74)

The Technical Committee identified the following research recommendations to improve the stock assessment and our understanding of tautog population and fishery dynamics. Research recommendations are organized by topic and level of priority. Research recommendations that should be completed before the next benchmark assessment are underlined.

8.3 Life History, Biological, and Habitat Priorities *Moderate*

- Define local and regional movement patterns and site fidelity in the southern part of the species range. This information may provide insight into questions of aggregation versus recruitment to artificial reef locations, and to clarify the need for local and regional assessment.
- Assemble regional reference collections of paired operculum and otolith samples and schedule regular exchanges to maintain and improve the precision of age readings between states that will be pooled in the regional age-length keys.
- Calibrate age readings every year by re-reading a subset of samples from previous years before ageing new samples. States that do not currently assess the precision of their age readings over time should do so by re-ageing a subset of their historical samples.

Low

- Evaluate the potential impacts of climate change on tautog range, life history, and productivity.
- Conduct a tag retention study to improve return rates, particularly in the northern region.
- Define the status (condition and extent) of optimum or suitable juvenile habitats and trends in specific areas important to the species. It is critical to protect these habitats or to stimulate restoration or enhancement, if required.
- Define the specific spawning and pre-spawning aggregating areas and wintering areas of juveniles and adults used by all major local populations, as well as the migration routes used by tautog to get to and from spawning and wintering areas and the criteria or times of use. This information is required to protect these areas from damage and overuse or excessive exploitation.

- Define larval diets and prey availability requirements. This information can be used as determinants of recruitment success and habitat function status. Information can also be used to support aquaculture ventures with this species.
- Define the role of prey type and availability in local juvenile/adult population dynamics over the species range. This information can explain differences in local abundance, movements, growth, fecundity, etc. Conduct studies in areas where the availability of primary prey, such as blue mussels or crabs, is dependent on annual recruitment, the effect of prey recruitment variability as a factor in tautog movements (to find better prey fields), mortality (greater predation exposure when leaving shelter to forage open bottom), and relationship between reef prey availability/quality on tautog condition/fecundity.
- Define the susceptibility of juveniles to coastal/anthropogenic contamination and resulting effects. This information can explain differences in local abundance, movements, growth, fecundity, and serve to support continued or increased regulation of the inputs of these contaminants and to assess potential damage. Since oil spills seem to be a too frequent coastal impact problem where juvenile tautog live, it may be helpful to conduct specific studies on effects of various fuel oils and typical exposure concentrations, at various seasonal temperatures and salinities. Studies should also be conducted to evaluate the effect of common piling treatment leachates and common antifouling paints on YOY tautog. The synergistic effects of leaked fuel, bilge water, treated pilings, and antifouling paints on tautog health should also be studied.
- Define the source of offshore eggs and larvae (in situ or washed out coastal spawning).
- Confirm that tautog, like cunner, hibernate in the winter, and in what areas and temperature thresholds, for how long, and if there are special habitat requirements during these times that should be protected or conserved from damage or disturbance. This information will aid in understanding behavior variability and harvest availability.

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FROM ORIGINAL FISHERY MANAGEMENT PLAN (1996):

1.2 DESCRIPTION OF THE RESOURCE

1.2.1.2. Habitat Needs (Page 2)

Post-larval tautog are found in association with structured habitats throughout their lives. These provide shelter during nightly dormant periods. When tautog are not feeding during the day, they can be found resting on sand or within shelter, lying quietly on their sides, often grouped together (Bigelow 1974). Juveniles require places to feed and to hide from predators. They are typically found in submerged vegetation, shellfish beds, and other structures for shelter, and locations where their food source of encrusting and bottom living organisms can be found. North of Long Island, New York, rocks and boulders left by glacial deposition can be found in abundance along the coastline, providing “reef” habitat for larger tautog. South of Long Island, there are few natural rocky habitats in coastal

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waters. Tautog in these southern areas commonly inhabit shellfish beds, coastal jetties, pilings, shipwrecks, and artificial reefs.

4.5 HABITAT CONSERVATION AND RESTORATION (pages 40-41)

Habitat conservation may be defined as protection of resource environmental quality while allowing wise use of the same resource (Edwards et al. 1992). Existing fishery habitat, for all life history stages, should be protected and preserved, rather than relying on habitat restoration programs that can be extremely expensive, difficult to fund, and only partially successful. Little can be done to prevent natural damage to habitats due to storms or other acts of nature. Therefore, the greatest benefits can be achieved through controlling human activities that damage habitat. Because coastal development will continue, however, it must be directed so that marine resources are still protected. Consideration should be given to switching from a single species approach to an ecosystem management approach that allows conservation of specific species and habitat types as well as whole biological communities with all of their biological components and diversity.

Information on biological, economic and social aspects of habitat conservation and restoration are necessary for informed decision making, but are often unavailable. Public outreach and awareness of habitat issues can be increased through readily available information on fishery habitat issues and through proactive educational programs. This outreach should target two general audiences: first, those specifically involved in activities that may lead to habitat degradation, such as marinas, dredgers and other industries; second, the general public for education concerning tautog life history, fisheries, and management. Greater awareness of the importance of habitat to all life history stages of tautog could increase compliance with regulatory requirements designed to conserve and restore habitat. In addition to fishery habitat loss, pollution and environmental degradation can have other indirect effects. Private property values may decline as a result of decreased aesthetic value and decreased recreational opportunities resulting from declines in water quality. Hotels and marinas are impacted by chemical and oil spills through decreased demand for degraded areas. Business losses to recreation-associated industries occur as a result of decreasing demand for boat design and construction, campers, sports equipment and recreational gear.

4.5.1 Preservation of Existing Habitat

Agencies having regulatory or review authority over habitat types identified as critical to tautog should consider protection of such habitats to benefit the management efforts of this Plan. Management of existing habitat on a sustainable basis requires a thorough knowledge of essential habitat types, their distribution, and their use by all life history stages of tautog. Currently, additional research is needed to determine the extent and condition of essential tautog habitats on a coastwide basis. Once the locations and abundance of essential tautog habitats are determined, control of how these habitats are used can begin. Marine refuges and special fishery management zones (SMZ) that limit fishing access and gear types are one potential method of habitat management.

4.5.2 Avoidance of Incompatible Activities

Each state should establish windows of compatibility for activities know, or suspected, to adversely affect tautog habitat and notify appropriate agencies in writing. Projects involving water withdrawal should be evaluated to ensure that impacts will not adversely affect tautog stocks. In addition, industrial facilities should be located such that entrainment of eggs and larvae in cooling water systems and mortality from thermal effects and physical disturbances are minimized. Any activities that physically alter habitat, such as dredging, bulk-heading and channel construction, could reduce tautog production. The impact of such activities on tautog spawning and nursery areas should be considered. As a preventative measure, buffer zones could be established around important nursery areas.

4.5.3 Fisheries Practices

Certain gear types may disrupt tautog habitat, however, insufficient information is available to quantify effects at this time. Any fishing gear having an unacceptable impact on tautog habitat should be prohibited within essential habitats.

4.5.4 Habitat Restoration, Improvement, and Enhancement

Habitat restoration involves restoring the usefulness of habitats adversely impacted by human activity or natural events. Determining the need for restoration of tautog habitat requires definition of critical or essential habitat types for all life history stages and quantification of the amount of habitat required to support the desired tautog abundance. Restoration should be considered where well-known, historically "productive" tautog habitat has been degraded or lost. This degradation or loss can be uncontrolled soil erosion, siltation, or accidental spills of toxic substances.

Restoration could be directed specifically toward tautog habitat or it could occur as a component of other efforts. South of Cape Cod, restoration of lobster habitat should also consider the needs of tautog because habitat usage by the two species overlaps. Response plans for accidental toxic spills in coastal waters should focus on tautog as well as shellfish resources, because tautog are localized and depend on specific habitats and associated food sources that are susceptible to chemical contamination.

Habitat improvement requires making tautog habitat better than it is presently. Tautog habitat could be improved by minimizing sewage discharges and increasing wastewater treatment levels near nursery areas. Existing industrial facilities should be retro-fitted with the best available technology to minimize facility-induced mortality of eggs and larvae. Larval stage assessments should be incorporated into the entrainment studies required of industrial facilities that withdraw coolant water from shallow water marine habitats. Non-point source toxic contamination of groundwater and nearshore coastal habitats can be reduced by redirecting storm water runoff into catch basins.

Habitat enhancement requires the creation or expansion of essential habitat where little or none presently exists. Creation of artificial reef habitats and breakwaters could mitigate habitat losses. Both intentional reef construction and accidental creation through shipwrecks may be expanding tautog habitat in open, sandy coastal areas where tautog would not normally be found.

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ATLANTIC STATES MARINE FISHERIES COMMISSION

2015 Action Plan

October 28, 2014

Goal 1 - Rebuild, maintain and fairly allocate Atlantic coastal fisheries

Goal 1 focuses on the responsibility of the states to conserve and manage Atlantic coastal fishery resources for sustainable use. Commission members will advocate decisions to achieve the long-term benefits of conservation, while balancing the socio-economic interests of coastal communities. Inherent in this is the recognition that healthy and vibrant resources mean more jobs and more opportunity for those that live along the coast. The states are committed to proactive management, with a focus on integrating ecosystem services, socio-economic impacts, habitat issues, bycatch and discard reduction measures, and protected species interactions into well-defined fishery management plans. Fishery management plans will also address fair (equitable) allocation of fishery resources among the states. Understanding global climate change and its impact on fishery productivity and distribution is an elevated priority. Improving cooperation and coordination with federal partners and stakeholders can streamline efficiency, transparency, and, ultimately, success. In the next five years, the Commission is committed to making significant progress on rebuilding overfished or depleted Atlantic fish stocks.

Strategies to Achieve Goal

1.1 Manage interstate resources that provide for productive, sustainable fisheries using sound science.

American Eel

Task 1.1.1 – Monitor and Implement Addendum III and IV (changes to the glass, silver and yellow eel fisheries).

Task 1.1.2 – Continue to work with Law Enforcement Committee (LEC) on monitoring poaching and illegal sale of glass eels (see Task 3.3.1).

Task 1.1.3 – Develop Memorandum of Understanding on management and scientific collaboration with Great Lakes Fishery Commission, U.S Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), and Canada Department of Fisheries and Oceans.

Task 1.1.4 – Monitor action by USFWS on the petition to list American eel under the Endangered Species Act. Monitor classification of eel under the Convention on the International Trade of Endangered Species (CITES) and on the International Union of Conservation of Nature (IUCN) Red List.

Task 1.1.5 – Monitor fishery for consistency with management program and state compliance.

Task 1.1.6 – Initiate collaboration with Canada Department of Fisheries and Oceans (DFO) on next stock assessment, based on the recommendations of the 2012 peer review panel to conduct a more inclusive range wide assessment.

Task 1.1.7 – Work with the technical committee to review and develop strategy to incorporate pertinent findings from the 2014 AFS eel symposium into future assessments and management decisions. Update the young of the year surveys with 2014 data. Work with the Technical Committee and Fish Passage working group to monitor eel mortality in turbines.

Task 1.1.8 Work with the technical committee and the fish passage work group to annually update the board on fish passage improvements and current issues including hydropower dam issues. States can use this information when leveraging partnerships to reduce passage impacts on eel and other anadromous species. (Task 2.2.1.4)

American Lobster

Task 1.1.9 – Monitor implementation of Addenda VII, VIII and XIX - XXII to establish measures to rebuild the Southern New England (SNE) stock. Develop an addendum to adjust the fishery effort to the size of the resource in Lobster Conservation Management Areas 4, 5, and 6.

Task 1.1.10 – Complete and implement Jonah Crab FMP, as directed, to ensure the long-term sustainability of the fishery.

Task 1.1.11 – Monitor the New England Fishery Management Council (NEFMC) actions on habitat area closures for impacts to the lobster fishery, respond if necessary.

Task 1.1.12 – Complete the 2015 benchmark stock assessment and consider management response to the assessment findings.

Task 1.1.13 – Explore long-term funding options for fishery-independent and dependent data collection.

Task 1.1.14 – Continue the development of the lobster trap database to track trap tag transfers.

Task 1.1.15 – Monitor fishery for consistency with management program and state compliance. Continue to work with the federal government to ensure consistency between regulations in state and federal waters. Implement a new addendum to address inconsistent state and federal lobster measures and propose consistent programs.

Task 1.1.16 – Update the ACCSP Data Warehouse with landings information and monitor landings patterns in both the trap and non-trap fisheries.

Task 1.1.17 – Continue to monitor progress towards implementing more complete catch reporting as recommended by the 2009 Stock Assessment Peer Review Panel.

Task 1.1.18 – Monitor trap tag production and distribution.

Atlantic Herring

Task 1.1.19 – Review 2015 specifications to determine if any changes are necessary. Review operational assessment results and consider management response to the assessment findings. Set specifications for 2016-2018.

Task 1.1.20 – Monitor activities of the NEFMC and the Mid-Atlantic Fishery Management Council (MAFMC) with regards to complementary FMP actions, including but not limited to management area boundaries, Amendment 5 issues and, river herring bycatch avoidance program. Consider complementary action where necessary.

Task 1.1.21 – Hold meetings as necessary to establish state effort control (days-out) programs for Areas 1A and 1B.

Task 1.1.22 – Finalize and implement measures included in Amendment 3, which proposes management options for spawning area efficacy, fixed gear rollover provision, and empty fish hold provision.

Task 1.1.23 – Monitor fishery for consistency with management program and state compliance.

Task 1.1.24 – Continue working with NEFSC to identify opportunities for offshore spawning sampling and analysis with particular interest in Nantucket Shoals.

Atlantic Menhaden

Task 1.1.25 – Review state compliance with implementation of Amendment 2. Review effectiveness of Amendment 2 including, bycatch provision, total allowable catch, and episodic event provisions. Complete 3 year review of total allowable catch and allocations for Amendment 2. Monitor landings for the 2015 fishing year.

Task 1.1.26 – Review results of 2014 benchmark stock assessment and consider management response to the assessment findings.

Task 1.1.27 – Continue to work with Technical Committee and Biological Ecological Reference Points (BERP) Working Group to present options for board consideration on ecosystem-based reference points that account for predation effects (See Task 2.4.1).

Atlantic Striped Bass

Task 1.1.28 – Implement and monitor Addendum IV, including conservation equivalency plans.

Task 1.1.29 – Continue the development of Chesapeake Bay reference points or an updated stock assessment, update data needs, and consider management response to findings.

Task 1.1.30 – Monitor fishery for consistency with management program and state compliance.

Atlantic Sturgeon

Task 1.1.31 – Continue development of the 2017 benchmark stock assessment. Collaborate with federal agencies to analyze bycatch data and prioritize/process genetic samples for use in the assessment.

Task 1.1.32 – Monitor state and federal activities in response to Endangered Species Act (ESA) listing of Atlantic sturgeon

Task 1.1.33 – Monitor fishery for consistency with management program and state compliance.

Bluefish

Task 1.1.34 – Work in collaboration with NMFS Northeast Fisheries Science Center (NEFSC) to complete 2015 benchmark stock assessment. Consider management response to the assessment findings in conjunction with MAFMC.

Task 1.1.35 – Establish specifications for 2016-2018 in cooperation with the MAFMC.

Task 1.1.36 – Monitor fishery for consistency with management program and state compliance.

Coastal Sharks

Task 1.1.37 – Establish specifications for 2016 and later.

Task 1.1.38 – Monitor and engage in the development of Amendment 6 (catch shares) by the NMFS Division of Highly Migratory Species (HMS). Determine appropriate Commission management response to HMS Amendments.

Task 1.1.39 – Monitor legislative initiatives on shark finning and respond if necessary.

Task 1.1.40 – Review and consider smoothhound benchmark stock assessment for management and consider management response to the assessment findings.

Task 1.1.41 – Monitor activities of NOAA and HMS with regards to coastal shark management actions for consistency.

Task 1.1.42 – Monitor fishery for consistency with management program and state compliance.

Horseshoe Crab

Task 1.1.43 – Review all possible data sources for the Adaptive Resource Management (ARM) Framework and determine if an alternate data source can be used in place of the Horseshoe Crab Benthic Trawl Survey data.

Task 1.1.44 – Complete and review artificial bait studies and consider management implications.

Task 1.1.45 – Establish the 2016 specifications using the ARM Framework and quota allocation methodology.

Task 1.1.46 – Engage federal stakeholders, the biomedical community, and shorebird interest groups to secure long-term funding to support data collection for use in the ARM Framework, including the Horseshoe Crab Benthic Trawl Survey.

Task 1.1.47 – Engage the biomedical community toward finding a solution regarding confidential data use in order to enhance stock assessments and scientific advice for management.

Task 1.1.48 – Monitor red knot listing under the ESA and consider management response.

Task 1.1.49 – Monitor fishery for consistency with management program and state compliance for both the bait and biomedical industries.

Northern Shrimp

Task 1.1.50 – Continue development of new assessment approaches in response to 2014 benchmark assessment results.

Task 1.1.51 – Finalize and implement measures included in Amendment 3 which proposes limited entry in the northern shrimp fishery.

Task 1.1.52 – Establish specifications for the 2015/2016 season.

Task 1.1.53 – Monitor fishery for consistency with management program and state compliance.

Shad and River Herring

Task 1.1.54 – Monitor activities of the NEFMC and the MAFMC management actions including but not limited to shad and river herring bycatch avoidance programs.

Task 1.1.55 – Work with management partners to coordinate coastwide river herring monitoring and habitat restoration workshops (River Herring Technical Expert Working Group, MAFMC Working Group, Atlantic Coastal Fish Habitat Partnership Working Group).

Task 1.1.56 – Review products of the River Herring Technical Expert Working Group and consider for management use.

Task 1.1.57 – Work with states in the implementation of sustainable fisheries plans or habitat plans as required by Amendment 3, if necessary.

Task 1.1.58 – Monitor fishery for consistency with management program and state compliance.

South Atlantic Species

Atlantic Croaker

Task 1.1.59 – Initiate the development of the 2016 benchmark stock assessment.

Task 1.1.60 – Complete annual update of the traffic light to determine if management changes are needed.

Task 1.1.61 – Monitor fishery for consistency with management program and state compliance.

Black Drum

Task 1.1.62 – Review the 2014 benchmark stock assessment and consider management response to the assessment findings.

Task 1.1.63 – Monitor fishery for consistency with management program and state compliance.

Red Drum

Task 1.1.64 – Complete the 2015 benchmark stock assessment and consider management response to the assessment findings.

Task 1.1.65 – Monitor fishery for consistency with management program and state compliance.

Spanish Mackerel

Task 1.1.66 – Evaluate results of the pilot program for seasonal exemptions in the commercial pound net fishery. Consider changes to the management program.

Task 1.1.67 – Monitor fishery for consistency with management program and state compliance.

Spot

Task 1.1.68 – Initiate the development of the 2016 benchmark stock assessment.

Task 1.1.69 – Complete annual update of the traffic light to determine if management changes are needed.

Task 1.1.70 – Monitor fishery for consistency with management program and state compliance.

Spotted Seatrout

Task 1.1.71 – Monitor fishery for consistency with management program and state compliance.

Spiny Dogfish

Task 1.1.72 – Establish multi-year specifications beginning in 2016/2017.

Task 1.1.73 – Participate in annual stock status update, as needed.

Task 1.1.74 – Monitor fishery for consistency with management program and state compliance.

Summer Flounder, Scup, and Black Sea Bass

Summer Flounder

Task 1.1.75 – Continue development of the comprehensive summer flounder amendment, considering changes to both commercial and recreational management in coordination with MAFMC. Complete management response to summer flounder recreational working group.

> Subtask 1.1.75.1 – Consider technical committee recommendations on climate change impacts on species distribution and allocation.

Task 1.1.76 – Finalize regulations for 2015 recreational fishery.

Task 1.1.77 – Establish 2016-2018 specifications in collaboration with the MAFMC.

Task 1.1.78 – Work in collaboration with NMFS NEFSC to complete a stock status update.

Task 1.1.7.9 – Work in collaboration with the MAFMC, NOAA, NEFSC and industry to determine the viability of a sex specific modeling approach.

Task 1.1.80 – Monitor fishery for consistency with management program and state compliance.

Scup

Task 1.1.81 – Collaborate with MAFMC to initiate an amendment to address recreational/commercial allocation as well as commercial winter/summer allocation in the scup fishery considering the results of the completed economic study.

Task 1.1.82 – Work in collaboration with NMFS NEFSC to complete the 2015 benchmark stock assessment. Consider management response to the assessment findings.

Task 1.1.83 – Finalize regulations for 2015 recreational fishery.

Task 1.1.84 – Establish 2016-2018 specifications in collaboration with the MAFMC.

Task 1.1.85 – Monitor fishery for consistency with management program and state compliance.

Black Sea Bass

Task 1.1.86 – Finalize regulations for 2015 recreational fishery. Consider initiation of addendum for recreational management measures for 2016 and later.
Task 1.1.85 – Establish 2016-2018 specifications in collaboration with the MAFMC.

Task 1.1.87 – In collaboration with the MAFMC and the NEFSC continue the 2016 benchmark stock assessment. Consider stock assessment update in 2015 if data become available.

Task 1.1.88 – Monitor fishery for consistency with management program and state compliance.

Tautog

Task 1.1.89 – Review results of 2014 benchmark stock assessment and consider management response to the assessment findings.

Task 1.1.90 – Monitor fishery for consistency with management program and state compliance.

Weakfish

Task 1.1.91 – Complete the 2015 benchmark stock assessment and update 2015 stock status indicators to evaluate changes in the population.

Task 1.1.92 – Review trends in landings and conduct annual review of conservation equivalency programs, if necessary.

Task 1.1.93 – Monitor fishery for consistency with management program and state compliance.

Winter Flounder

Task 1.1.94 – Monitor NEFSC stock assessment activities for inshore winter flounder stocks and set specifications for 2016-2018.

Task 1.1.95 – Continue to monitor federal water common pool landings and regulations. Review state water landings and make changes to fishery specifications if necessary.

Task 1.1.96 – Monitor fishery for consistency with management program and state compliance.

1.2 Strengthen state and federal partnerships to improve comprehensive management of shared fishery resources.

Task 1.2.1 – Participate as a non-voting member and liaison between the Regional Fishery Management Councils and the Commission on matters of mutual interest.

Task 1.2.2 – Participate on the Northeast Regional Coordinating Council and SouthEast Data, Assessment and Review (SEDAR) Steering Committee to set state/federal management and assessment priorities

Task 1.2.3 – Work with the Regional Fishery Management Councils and NMFS to improve alignment between state and federal fishery management programs.

Task 1.2.4 – Work with NOAA Headquarters and regional leadership to improve alignment of state/federal budget priorities.

Task 1.2.5 – Continue to work with NEFMC and MAFMC on evaluating and mitigating shad and river herring bycatch (See Task 1.1.53).

1.3 Adapt management to address emerging issues.

Task 1.3.1 – Continue to monitor developments related to climate change, stock distributions, ocean planning, and potential fisheries reallocations.

Task 1.3.3 – Identify common resource issues – protected species interactions, bycatch/discards, shifting population distributions, ecosystem services – that are cross-cutting among the Commission's interstate fishery management plans.

1.4 Practice efficient, transparent, and accountable management processes.

Task 1.4.1 – Continue to track status of stocks relative to biological reference points to evaluate and drive improvement and results in the Commission's fisheries management process.

Task 1.4.2 – Continue the use of decision documents and working groups to structure Board discussion on complex management decisions and increase transparency of pending board action.

Task 1.4.3 – Continue to focus Board attention on developing clear problem statements prior to initiating management changes.

Task 1.4.4 – Continue to use roll call voting procedures for Commission final actions.

1.5 Evaluate progress towards rebuilding fisheries.

Task 1.5.1 – Conduct annual Commissioner assessment of progress towards achieving the Commission's mission, vision and goals using an on-line survey.

Task 1.5.2 – Continue the use of the annual performance of the stock to evaluate species rebuilding progress.

1.6 Strengthen interactions and input among stakeholders, technical, advisory, and management groups.

Task 1.6.1 – Engage American lobster, summer flounder, scup, black sea bass, tautog, menhaden and northern shrimp advisory panels (APs) in the development of FMPs and Amendments. Solicit state membership of current active APs and appoint new membership where necessary.

Subtask 1.6.1.1 – Finalize reconfiguration of combined AP for summer flounder, scup, and black sea bass and improve AP input process with MAFMC.

Task 1.6.2 – Continue communication with non-active advisory panels (species in the maintenance mode).

Task 1.6.3 – Integrate non-traditional constituents into all Advisory Panels (See Task 5.2.3).

Goal 2 – Provide the scientific foundation for and conduct stock assessments to support informed management actions

Sustainable management of fisheries relies on accurate and timely scientific advice. The Commission strives to produce sound, actionable science through a technically rigorous, independently peer-reviewed stock assessment process. Assessments are developed using a broad suite of fishery-independent surveys and fishery-dependent monitoring, as well as research products developed by a vast network of fisheries scientists at state, federal, and academic institutions along the coast. The goal encompasses the development of new, innovative scientific research and methodology, and the enhancement of the states' stock assessment capabilities. It provides for the administration, coordination, and expansion of collaborative research and data collection programs. Achieving the goal will ensure sound science is available to serve as the foundation for the Commission's evaluation of stock status and adaptive management actions.

Strategies to Achieve Goal

2.1 Conduct stock assessments based on comprehensive data sources and rigorous technical analysis.

Task 2.1.1 – Address data priorities for stocks of unknown status. Continue development of the Atlantic sturgeon benchmark stock assessment and initiate the spot benchmark stock assessment.

Task 2.1.2 – Address data priorities for species with limited data. Collect more comprehensive information for data poor species in order to move from problematic to more accurate assessment models. Focal areas include sciaenid bycatch data, black sea bass fishery-dependent data, menhaden fishery-independent data, river herring at-sea and in-river monitoring, improved tautog indices, black drum biological sampling and fishery-independent monitoring of mature fish, and American eel surveys covering all life stages. Initiate benchmark stock assessment for Atlantic croaker.

Task 2.1.3 – Complete benchmark stock assessments for American lobster, weakfish, scup, red drum, and bluefish; complete operational assessment for Atlantic herring.

Task 2.1.4 – Facilitate independent peer reviews of the American lobster and weakfish assessments to provide sound, actionable scientific advice to managers. Complete SEDAR assessment review for red drum, and SARC reviews of scup and bluefish.

Task 2.1.5 – Through the Assessment Science Committee (ASC) and Management and Science Committee (MSC), develop the long-term stock assessment and peer review schedule to prioritize stocks by management need; present tradeoffs to the Policy Board when assessment scheduling changes are requested.

Task 2.1.6 – Track assessment scientists' workloads in order to complete 2015-2016 stock assessments; using the guidance of the ASC, develop new policies and approaches to better match assessment demand with assessment workload.

Task 2.1.7 – Following benchmark stock assessments, create species-specific digital archives (including CDs) to facilitate efficient assessment updates in the future.

Task 2.1.8 – Serve as members of the American Lobster, Weakfish, Atlantic Sturgeon, Multispecies, Scup, Black Sea Bass, Red Drum, Spot, Atlantic Croaker, and Bluefish Technical Committees and Stock Assessment Subcommittees to assist in completion of benchmark assessments and annual assessment updates. Utilize the Assessment Science Committee for guidance with assessment methods as necessary.

Task 2.1.9 – Continue to work with state and federal stock assessment scientists and staff of the Atlantic Coastal Cooperative Statistics Program (ACCSP) to increase use of ACCSP data in the Commission's technical work.

Task 2.1.10 – Through the MSC, and using ASC guidance, develop a Commission policy regarding risk and uncertainty, in consideration of Council approaches, and provide to the ISFMP Policy Board consideration.

2.2 Proactively address research priorities through cooperative state and regional data collection programs and collaborative research projects

Task 2.2.1 – Maintain the master list of ASMFC Research Priorities by species as benchmark assessments are completed and new priorities emerge.

Task 2.2.2 – Participate in proposal reviews for MARFIN, MARMAP, NMFS Cooperative Research Programs, Saltonstall-Kennedy and ACCSP, when requested, to evaluate projects and monitor regional research activities to promote member state needs.

Subtask 2.2.2.1 – Develop and communicate research priorities for review and approval by species management boards, and provide to funding programs.

Subtask 2.2.2.2 – Work closely with federal partners to ensure completed funded projects are reviewed and transmitted to appropriate technical committees and boards.

Task 2.2.3 – Communicate with the National Fish and Wildlife Foundation (NFWF) to review research priorities and funding opportunities (e.g., fish passage, catch shares).

Subtask 2.2.3.1 – Participate in NFWF proposal reviews for the Fisheries Innovation and River Herring Initiatives.

Task 2.2.4 – Participate on the ACCSP's Coordinating Council, Operations Committee, Bycatch Prioritization Committee, Biological Review Panel, Recreational and Commercial Technical Committees, Outreach Committee and the Computer Technical Committee.

Subtask 2.2.4.1 – Submit ASMFC changes to existing priorities for at-sea observer coverage for inclusion in the ACCSP Bycatch Prioritization Listing. Consult Fishing Gear Technology Work Group regarding ASMFC input to Bycatch Prioritization.

Task 2.2.5 – Coordinate and implement the Northeast Area Monitoring and Assessment Program (NEAMAP).

Subtask 2.2.5.1 – Administer funding to conduct 2015 NEAMAP Nearshore Trawl Surveys.

Subtask 2.2.5.2 – Support continuation of the NEAMAP Nearshore Trawl Surveys through coordination with survey leads and all NEAMAP committees: NEAMAP Board, Operations, Data Management, Analytical, and Trawl Technical Committees.

Subtask 2.2.5.3 – Develop the 2016 NEAMAP Operations Plan.

Subtask 2.2.5.4 – Conduct the collaborative NEAMAP/SEAMAP Catch Processing and Trawl Technology Workshops to compare methods and seek consistencies among all state and NEAMAP/SEAMAP surveys.

Subtask 2.2.5.5 – Provide NEAMAP data to coastwide stock assessments; track and demonstrate data use, and report to the ISFMP Policy Board; maintain the NEAMAP website as a tool for distributing program information and requesting data.

Subtask 2.2.5.6 – Seek opportunities and resources for NEAMAP sampling to supplement horseshoe crab data collection for the Delaware Bay population.

Task 2.2.6 – Coordinate the South Atlantic component of the Southeast Area Monitoring and Assessment Program (SEAMAP).

Subtask 2.2.6.1 – Coordinate all research components of SEAMAP-South Atlantic: Coastal Trawl Survey, Red Drum Longline Surveys, Bottom Mapping, Fish Habitat Characterization and Assessment, Pamlico Sound Survey, Reef Fish Survey, Southeast Regional Taxonomic Center, Cooperative Winter Tagging Cruise, and the Data Management and Crustacean Work Groups.

Subtask 2.2.6.2 – Coordinate the development of the next 5-year SEAMAP Management Plan (2016-2020); maintain the SEAMAP website hosted by ASMFC.

Subtask 2.2.6.3 – Participate in the expansion of SEAMAP-South Atlantic fishery-independent data coordination and mapping, as resources allow.

Subtask 2.2.6.4 – Coordinate South Atlantic activities with the Gulf and Caribbean components of SEAMAP.

Task 2.2.7 – Continue the Tagging Certification Program and support the use of tagging data in ASMFC stock assessments. Develop tagging registration programs, update and maintain the tagging resource website, link acoustic tagging information to the Atlantic Coastal Tagging (ACT) network website, and develop instructional tagging videos to improve the efficiency and quality of tagging efforts along the coast.

Task 2.2.8 – Develop long-term strategy for collecting striped bass tagging data, including funding, administration, and at-sea support.

Task 2.2.9 – Continue to participate in the development and implementation of the Marine Recreational Information Program (MRIP), with ASMFC staff serving on Executive Steering Committee, Operations Team, Transition Team, and Angler Registry Team. Report progress to the ISFMP Policy Board, and scientific oversight committees (MSC, ASC).

Task 2.2.10 – Coordinate the fish ageing activities among Atlantic coast states and university laboratories in order to provide consistent, accurate age data to stock assessments.

Subtask 2.2.10.1 – Conduct age sample exchanges and an ageing workshop for Atlantic menhaden to prepare ageing laboratories for providing new age data consistent with historical age data.

Subtask 2.2.10.2 – Conduct an annual ageing quality control workshop using age sample reference collections for multiple species to maintain consistency among state and university ageing technicians.

Subtask 2.2.10.3 – Continue cooperative angler programs with the states to collect age samples toward improving age data for assessments.

Subtask 2.2.10.4 – Collaborate with the Gulf States Marine Fisheries Commission to develop an ageing manual with fish ageing protocols for Atlantic coast and Gulf coast species.

Task 2.2.11 – Continue coordination of the ASMFC Observer Program for Mid-Atlantic small-mesh otter trawl fisheries through the Northeast Fishery Observer Program. Pursue funding with other partners; expand the program to address other ASMFC research priorities, based upon the ACCSP FY2015 Bycatch Prioritization Listing. Evaluate existing funding mechanisms that use industry support.

Task 2.2.12 – Continue to support monitoring and other data collection to improve information available for assessments of spot, kingfish (whiting) and black drum. Support improved monitoring of blue catfish in collaboration with NOAA Chesapeake Bay Office.

Task 2.2.13 – Coordinate the activities of the Committee on Economics and Social Sciences (CESS).

> Subtask 2.2.13.1 – Develop socioeconomic analyses and advice in conjunction with stock assessments to provide more comprehensive information for managers when making harvest and allocation decisions; develop socioeconomic analysis for Atlantic menhaden in 2015.
>
> Subtask 2.2.13.2 – Report to ISFMP Policy Board on current socioeconomic data collection and analyses used by other Commissions and Councils, including associated costs.
>
> Subtask 2.2.13.3 – Track progress of NEFSC's development of fishery performance measures to evaluate fishing community success.
>
> Subtask 2.2.13.4 – Cooperate with ACCSP staff on issues requiring socioeconomic data. Provide recommendations on socioeconomic data collection and standards.

Task 2.2.14 – Coordinate the activities of the Fish Passage Working Group (FPWG) to carry out priority tasks as defined by the ISFMP Policy Board. Promote development of effective fish passage approaches and projects through state and federal collaboration.

> Subtask 2.2.14.1 – Maintain a coastwide database of dams, dam removals, fishways, and passage efficiency studies. Collaborate with NGOs to incorporate the database in their passage prioritization tools.
>
> Subtask 2.2.14.2 – Implement the fish passage prioritization protocol, maintain a coastwide list of passage project priorities, and develop performance criteria to evaluate passage projects' success.
>
> Subtask 2.2.14.3 – Establish coastwide fish passage targets and add to diadromous species FMPs as amendments/addenda are developed.
>
> Subtask 2.2.14.4 – Monitor and participate in upcoming FERC relicensing projects; develop guidance for state staff for navigating the FERC dam relicensing process, in order to more effectively improve passage in relicensing prescriptions.
>
> Subtask 2.2.14.5 – Continue to develop an East Coast Fish Passage Plan.
>
> Subtask 2.2.14.6 – Evaluate positive and negative consequences of providing fish passage through consultation with the diadromous technical committees.

2.3 Facilitate stakeholder involvement in research initiatives and the stock assessment process.

Task 2.3.1 – Facilitate stakeholder participation in the stock assessment and fisheries management processes. Seek stakeholder input at data workshops during development of stock assessments.

Task 2.3.2 – Promote scientifically sound tagging practices and certification of angler-based tagging programs through the Interstate Tagging Committee.

Task 2.3.3 – Develop outreach materials that highlight opportunities for public engagement in the Commission's fisheries management and stock assessment processes (See Task 5.2.4).

2.4 Promote data collection and research to support ecosystem-based management

Task 2.4.1 – Ecological Reference Points Working Group develop and present options for board consideration on ecosystem-based reference points that account for predation effects (See Task 1.1.26).

Task 2.4.2 – Continue to improve multispecies modeling efforts to support single-species assessments, including development of a new multispecies statistical catch-at-age model. Examine ecosystem based reference points as an alternative to single species reference points, using Atlantic menhaden as a test species.

Task 2.4.3 – Identify opportunities to collaborate with state, federal, and university researchers to use existing data collection platforms to advance ASMFC ecosystem models (e.g. diet studies, surveys of spawning and nursery habitats).

Task 2.4.4 – Identify common resource issues - protected species interactions, bycatch/discards, shifting population distributions, ecosystem services – that are cross-cutting among the Commission's interstate fishery management plans. Develop recommendations for ISFMP Policy Board consideration to address common issues while maintaining sustainable fisheries in state waters.

Task 2.4.5 – Convene the Fishing Gear Technology Work Group to evaluate the efficacy of Bycatch Reduction Devices in southern shrimp trawl fisheries to reduce Sciaenid bycatch.

Task 2.4.6 – Participate as members of the Chesapeake Bay Sustainable Fisheries Goal Implementation Team and Forage Fish Workgroup.

2.5 Provide stock assessment training to improve the expertise and involvement of state and staff scientists.

Task 2.5.1 – Conduct intermediate and advanced stock assessment methods training workshops. Conduct a stock assessment training workshop for Commissioners (See Task 7.3.5).

Task 2.5.2 – Support external stock assessment training opportunities for staff and state scientists.

Goal 3 – Promote compliance with fishery management plans to ensure sustainable use of Atlantic coast fisheries

Fisheries managers, law enforcement personnel, and stakeholders have a shared responsibility to promote compliance with fisheries management measures. Activities under the goal seek to increase and improve compliance with fishery management plans. This requires the successful coordination of both management and enforcement activities among state and federal agencies. Commission members recognize that adequate and consistent enforcement of fisheries rules is required to keep pace with increasingly complex management activity and emerging technologies. Achieving the goal will improve the effectiveness of the Commission's fishery management plans.

Strategies to Achieve Goal

3.1 Develop practical compliance requirements that foster stakeholder buy-in.

Task 3.1.1 – Identify and explore fishery management measures that maximize stakeholder buy-in.

3.2 Evaluate the enforceability of management measures and the effectiveness of law enforcement programs.

Task 3.2.1 – Work with Law Enforcement Committee (LEC) Coordinator to ensure the input of the LEC throughout the management process on the enforceability of management options proposed in FMPs, amendments, addenda and conservation equivalency proposals.

Task 3.2.2 – Review effectiveness of the "Guidelines for Resource Managers" to evaluate its ability to inform fishery managers and affect their decisions in the regulatory process.

Task 3.2.3 – Report on the enforceability of existing FMPs as part of the annual compliance review for each species.

Task 3.2.4 – Engage and support NMFS, USFWS Offices of Law Enforcement, and USCG to improve communication and coordination between states and federal enforcement agencies.

3.3 Promote coordination and expand existing partnerships with state and federal natural resource law enforcement agencies.

Task 3.3.1 – Provide a forum to promote interjurisdictional enforcement operations targeting specific fishery resources (e.g. Atlantic striped bass, tautog, American eel) (see Task 1.1.2).

Task 3.3.2 – Expand efforts to reach out to the law enforcement advisory committees of the regional fishery management councils and interstate commissions to seek opportunities for collaboration and ensure consistent law enforcement strategies.

Task 3.3.3 – Continue to evaluate the states' use of vessel monitoring system (VMS) data with increased access provided to the states. Determine if current level of access is adequate for state use of VMS data. Provide training opportunities, if necessary and resources permit, for state officers to ensure timely and efficient access to VMS data.

Task 3.3.4 – Monitor the Conservation Law Enforcement Chiefs Association and Association of Fish and Wildlife Agencies' Law Enforcement Committee and exchange information as appropriate.

Task 3.3.5 – Exchange information on record keeping of violations, dispatching, and use of real time data to enhance conservation enforcement efforts.

Task 3.3.6 – Exchange information and best practices related to the enforcement of protected and endangered species regulations

Task 3.3.8 – Develop strategies to improve communications among state and federal enforcement agencies prior to regional enforcement activities.

Task 3.3.9 – Engage in annual review of NMFS enforcement priorities to ensure state enforcement needs are included. Review and provide feedback to NMFS on the federal penalty structure.

Task 3.3.10 – Provide feedback to NMFS as additional electronic monitoring technologies are considered and adopted.

Task 3.3.11 – Conduct semi-annual presentations, by state and federal agencies, of enforcement actions and facilitate discussions on joint efforts that can assist in fisheries enforcement.

Task 3.3.12 – Share enforcement techniques and law enforcement success stories and provide regional training sessions (if resources allow) to enhance law enforcement efficiency along the Atlantic coast.

Task 3.3.13 – Evaluate the merits of establishing more timely communication among state and federal law enforcement entities to facilitate more frequent information exchange.

Task 3.3.14 – Assist MAFMC in identifying strategies to address violations and illegal harvest involved in Research Set-Aside.

3.4 Enhance stakeholder awareness of management measures through education and outreach.

Task 3.4.1 – Continue to highlight the outcomes of law enforcement investigations (penalties and fines) through various outreach tools (website, social media, press releases, fact sheets).

3.5 Use emerging communication platforms to deliver real time information regarding regulations and the outcomes of law enforcement investigations.

Task 3.5.1 – Report on enforcement issues associated with differing federal, interstate, and state regulations using social media and timely press releases.

Task 3.5.2 – Provide forum for enforcement agencies to display successful development and use of enforcement technologies.

Goal 4 – Protect and enhance fish habitat and ecosystem health through partnerships and education

Goal 4 aims to conserve and improve coastal, marine, and riverine habitat to enhance the benefits of sustainable Atlantic coastal fisheries and resilient coastal communities in the face of changing ecosystems. Habitat loss and degradation have been identified as significant factors affecting the long-term sustainability and productivity of our nation's fisheries. The Commission's Habitat Program develops objectives, sets priorities, and produces tools to guide fisheries habitat conservation efforts directed towards ecosystem-based management.

The challenge for the Commission and its state members is maintaining fish habitat in the absence of specific regulatory authority for habitat protection or enhancement. Therefore, the Commission will work cooperatively with state, federal, and stakeholder partnerships to achieve this goal. The Commission and its Habitat Program endorses the National Fish Habitat Partnership, and will continue to work cooperatively with the program to improve aquatic habitat along the Atlantic coast. Since 2008, the Commission has invested considerable resources, as both a partner and administrative home, to the Atlantic Coastal Fish Habitat Partnership (ACFHP), a coastwide collaborative effort to accelerate the conservation and restoration of habitat for native Atlantic coastal, estuarine-dependent, and diadromous fishes.

Strategies to Achieve Goal

4.1 Identify critical habitat through fisheries management programs and partnerships.

Task 4.1.1 – Finalize the sciaenid habitat source document working closely with technical committees, other species experts, and staff.

Task 4.1.2 – Prioritize and publicize important habitat types for Commission-managed species as identified in the ACFHP Strategic Plan and Habitat Committee Guidance Document.

Task 4.1.3 – Update species habitat factsheets for publishing in early 2015.

Task 4.1.4 – Coordinate artificial reef activities among the Atlantic coast states, and between the Atlantic and Gulf States Marine Fisheries Commissions.

4.2 Educate Commissioners, stakeholders, and the general public about the importance of habitat to healthy fisheries and ecosystems.

Task 4.2.1 – Facilitate coordination and distribution of information for ecosystem-based management and marine protected area activities, and the potential consequences of significant anthropogenic activities on habitats of concern.

Task 4.2.2 – Participate in regional and national habitat meetings and scientific conferences to facilitate increased communication with agencies and programs that have jurisdiction over habitat.

Task 4.2.3 – Publish annual issue of *Habitat Hotline Atlantic*.

Task 4.2.4 – Develop next installment of the Habitat Management Series: *Climate Change Impacts on Fish Habitats* for ISFMP Policy Board review and acceptance. Identify a subsequent topic (e.g. Sand mining, Power plant impingement).

4.3 Engage local, state and regional governments in mutually beneficial habitat protection and enhancement programs through partnerships

Task 4.3.1 – Work with ACFHP to foster partnerships with like-minded organizations at local levels to further common habitat goals.

Task 4.3.2 – Provide stakeholders with the tools to effectively communicate, promote and accomplish habitat protection, restoration, and enhancement programs at the local level.

Task 4.3.3 – Serve as a point of contact and information conduit at the Commission for energy-related issues affecting fish habitat.

Task 4.3.4 – Continue to provide coordination support for ACFHP, under the direction of the National Fish Habitat Action Plan (NFHAP) Board.

Subtask 4.3.4.1 – Facilitate communication and outreach with ACFHP partners, overlapping partnerships, and new partners. Develop outreach materials and maintain the ACFHP website.

Subtask 4.3.4.2 – Coordinate the implementation of the 5-year ACFHP Conservation Strategic Plan, including development of an Implementation Plan outlining tasks by year to achieve the goals, objectives, and actions in the Strategic Plan.

Subtask 4.3.4.3 – Support the completion of priority ACFHP Science and Data projects - acquire and analyze fish population, habitat, and human impact data; complete winter flounder GIS habitat assessment and initiate river herring habitat assessment; make results available to Partners for the purpose of strategic coastal habitat conservation.

Subtask 4.3.4.4 – Through ACFHP, and in cooperation with other Fish Habitat Partnerships and the National Fish Habitat Board, work with partners to develop monitoring and data standards for assessment of coastal habitat condition and fishery resource status prior to and following alteration projects.

4.4 Foster partnerships with management agencies, researchers, and habitat stakeholders to leverage regulatory, political, and financial support.

Task 4.4.1 – Provide information or comment on Atlantic coast projects and permits in accordance with ASMFC project review protocol.

Task 4.4.2 – Facilitate funding and partnership opportunities to promote habitat research in the states.

Task 4.4.3 – Identify partnership opportunities and forge additional relationships with organizations – such as non-governmental organizations and the recreational fishing community – to facilitate the promotion of fish habitat through a collaboration of strengths of different stakeholder groups.

Task 4.4.5 – Maintain habitat managers network to disseminate information about important habitat areas identified in Habitat Committee products. Use social media to connect with regional and local decision makers.

4.5 Identify mechanisms to evaluate ecosystem health.

Task 4.5.1 – Review habitat program goals and evaluate accomplishments annually.

Task 4.5.2 – Work with state and federal agencies, the Councils, and non-governmental organizations to build on existing efforts to populate coastwide GIS databases of fish habitat resources, to identify important fish habitats for Commission managed species as defined in the ACFHP Species-Habitat matrix.

4.6 Engage in state and federal agency efforts to ensure climate change response strategies are included in habitat conservation efforts.

Task 4.6.1 – As revisions to habitat sections of FMPs are made include recommendations to mitigate climate change impacts on habitat.

Task 4.6.2 – Identify inconsistencies in state coastal regulatory planning programs and develop recommendations for improvements to the ISFMP Board.

Goal 5 – Strengthen stakeholder and public support for the Commission

Stakeholder and public acceptance of Commission decisions are critical to our ultimate success. For the Commission to be effective, these groups must have a clear understanding of our mission, vision, and decision-making processes. The goal seeks to do so through expanded outreach and education efforts about Commission programs, decision-making processes, and its management successes and challenges. It aims to engage stakeholders in the process of fisheries management, and promote the activities and accomplishments of the Commission. Achieving the goal will increase stakeholder participation, understanding, and acceptance of Commission activities.

Strategies to Achieve Goal

5.1 Increase public understanding and support of activities through expanded outreach at the local, state, and federal levels.

Task 5.1.1 – Publish bi-monthly issues of *Fisheries Focus*. Continue to reduce mailing/printing costs through greater electronic distribution.

Task 5.1.2 – Use website to promote ASMFC activities to state and federal partners and stakeholders.

Task 5.1.3 – Promote ASMFC through attendance at fisheries-related trade shows and conferences.

Task 5.1.4 – Promote Commission activities regarding recently assessed and/or high profile species, habitat and law enforcement activities, as well as emerging issues such as fishery allocations and shifting populations due to climate change, to a broader constituency through mechanisms such as targeted press releases, informational brochures, webpage highlights and conference/trade show participation.

Task 5.1.5 – Develop and distribute youth-based educational materials designed to increase awareness of fisheries science and understating of fisheries management to key venues (e.g., teacher kits, Eco-camps, charter boat operations, aquatic educators) to help promote marine stewardship and ocean literacy.

Task 5.1.6 – Collaborate with three East Coast Aquaria (MD, VA and NC) and relevant partners to promote interstate fisheries management and science activities at the aquaria.

Task 5.1.7 – Promote Commission's mission and programs through outreach meetings with various marine policy and marine science graduate programs.

Task 5.1.8 – Participate in the Mid-Atlantic and New England Fishery Management Councils Marine Resource Education Program.

Task 5.1.10 – Conduct Fisheries Science 101 webinars to increase stakeholder and public understanding of basic fisheries science principles and concepts.

Task 5.1.9 – Prepare benchmark stock assessment board presentations (American lobster, Atlantic menhaden, tautog and red drum) for posting on YouTube and ASMFC Fisheries Science webpage.

5.2 Clearly define Commission processes to facilitate stakeholder participation, as well as transparency and accountability.

Task 5.2.1 – Publish and distribute 2014 Annual Report to Congress, state legislators, and stakeholders to provide overview of our activities and progress in carrying out the Commission's mission and public trust responsibilities.

Task 5.2.2 – Prepare Stock Assessment Briefs (in layman's terms) for major benchmark stock assessments to facilitate stakeholder understanding of the science behind our management decisions. Focal species for 2015 are American lobster, Atlantic menhaden, black drum, bluefish, weakfish, and tautog.

Task 5.2.3 – Enhance engagement in advisory panels and through solicitation of new members and increased participation of existing members (See Tasks 1.6.1 and 1.6.3).

Task 5.2.4 – Develop outreach materials that highlight opportunities for public engagement in the Commission's fisheries management and stock assessment processes

Task 5.2.5 – Develop a guide to fisheries management entities along the Atlantic coast.

5.3 Strengthen national, regional, and local media relations to increase coverage of Commission actions.

Task 5.3.1 – Track media communications and coverage through ASMFC-related news clippings and media tracking sheet.

Task 5.3.2 – Continue to work with key staff members on refining interview skills, with an emphasis on live, on-the-air interviews.

Task 5.3.3 – Conduct annual meeting of Atlantic Coast Fisheries Communication Group, comprised of Public Information Officers from the Councils, states and federal agencies, to share successful tools, identify key media contacts and work cooperatively on joint projects.

5.4 Use new technologies and communication platforms to more fully engage the broader public in the Commission's activities and actions.

Task 5.4.1 – Use social media tools to increase ASMFC visibility and improve stakeholder engagement.

Task 5.4.2. – Use website capabilities (e.g., video clips) to promote Fisheries Science 101 webinars, videos of fisheries surveys and state on-the-ground projects.

Task 5.4.3 – Evaluate the success of website and social media platforms in reaching broader constituency and effectively communicating ASMFC mission, programs and activities.

Goal 6 – Advance Commission and member states' priorities through a proactive legislative policy agenda

Although states are positioned to achieve many of the national goals for marine fisheries through cooperative efforts, state fisheries interests are often underrepresented at the national level. This is due, in part, to the fact that policy formulation is often disconnected from the processes that provide the support, organization, and resources necessary to implement the policies. The capabilities and input of the states are an important aspect of developing national fisheries policy, and the goal seeks to increase the states' role in national policy formulation. Additionally, the goal emphasizes the importance of achieving management goals consistent with productive commercial and recreational fisheries and healthy ecosystems.

The Commission recognizes the need to work with Congress in all phases of policy formulation. Several important fishery-related laws will be reauthorized over the next couple of years (i.e., Atlantic Coastal Act, Magnuson-Stevens Fishery Conservation and Management Act, Interjurisdictional Fisheries Act, Atlantic Striped Bass Conservation Act, and Anadromous Fish Conservation Act). The Commission will be vigilant in advancing the states' interests to Congress as these laws are reauthorized and other fishery-related pieces of legislation are considered.

Strategies to Achieve Goal

6.1 Increase the Commission's profile and support in the U.S. Congress by developing relationships between Members and their staff and Commissioners, the Executive Director, and Commission staff.

Task 6.1.1 – Provide opportunities for in person Commissioner interactions with Members and congressional staff at our Winter and Spring Meetings.

Task 6.1.2 – Provide opportunities for the Executive Director to meet with congressional staff on a regular basis.

Task 6.1.3 – Focus interactions on Members of Congress from Atlantic coast states that serve on committees of importance to the Commission:

- House and Senate Commerce Justice, Science Appropriations Subcommittees
- House Fisheries, Wildlife, Oceans and Insular Affairs Subcommittee of the Natural Resources Committee
- Senate Oceans, Atmosphere, Fisheries and Coast Guard Subcommittee of the Commerce, Science, and Transportation Committee

6.2 Communicate the Commission's federal funding needs to Congress and advocate for sufficient appropriations.

Task 6.2.1 – Clearly convey our funding needs as part of our communication with congressional staff.

Task 6.2.2 – Justify the need for federal dollars by the Commission through demonstrating the social, economic, and ecological benefits of Commission activities.

Task 6.2.3 – Work with Commissioners to identify funding needs and develop a strategy to secure funding for priority programs (Atlantic Striped Bass Conservation Act, Atlantic Coastal Fisheries Cooperative Management Act, Interjurisdictional Fisheries Act Grants, Stock Assessments line item, Federal Aid in Sport Fish Restoration, and Atlantic Coastal Fish Habitat Partnership).

Task 6.2.4 – Demonstrate the value of the Commission as an effective management entity and resource to Members of Congress and their staffs.

Task 6.2.5 – Provide state-specific perspectives to staff and Members in meetings, especially management successes and challenges.

Task 6.2.6 – Contact home state Commissioners before communicating with Members or Congressional staff to get a local perspective.

Task 6.2.7 – Coordinate with the Gulf, Pacific, and Great Lakes Commissions on policy items of mutual interest including federal funding for fisheries programs. Executive Directors should continue providing unified positions on funding and legislative priorities to lawmakers and federal agencies.

Task 6.2.8 – Coordinate with NMFS to pursue increased funding opportunities for Commission programs.

6.3 Engage Congress on fishery-related legislation affecting the Atlantic coast.

Task 6.3.1 – Monitor federal legislation affecting the Commission, including policy and annual appropriations bills and develop Commission positions on pending federal legislation (e.g., Magnuson-Stevens Reauthorization Act).

Task 6.3.2 – Update Commissioners on pending congressional actions that may affect fisheries management as appropriate.

Task 6.3.3 – Coordinate with the Legislative Committee and Government Relations firm to identify relevant policy and legislative issues.

Task 6.3.4 – Monitor congressional hearings related to fisheries issues, and testify or provide statements for the record when appropriate.

Task 6.3.5 – Engage Commissioners in the formulation of the Commission's position on federal legislative policy.

6.4 Promote member states' collective interests at the regional and national levels

Task 6.4.1 – Communicate member states' needs to Congress and our management partners.

Subtask 6.4.1.1 – Contact Commissioners before and after congressional meetings.

Subtask 6.4.1.2 – Facilitate opportunities for Legislators and Governors' Appointees to communicate directly with their Legislators and staff.

Task 6.4.2 – Participate with national organizations and management partners to address issues of mutual interest.

Subtask 6.4.2.1 – Conduct interagency coordination meetings (Memorandum of Understanding) under ACFCMA to improve state-federal partnerships.

Subtask 6.4.2.2 – Continue to serve as an advisor to Marine Fisheries Advisory Committee (MAFAC).

Subtask 6.4.2.3 – Continue to participate as a member on the Marine Fisheries Initiative (MARFIN) panel.

6.5 Promote economic benefits of the Commission's actions (return on investment).

Task 6.5.1 – Provide state-specific economic and jobs statistics related to commercial and recreational marine fishing to lawmakers and staff.

Task 6.5.2 – Use specific examples to show successful management can be linked to economic success and increased jobs.

Task 6.5.3 – Demonstrate the differences between federal and state fishery management tools and the economic benefits of the state management approach (flexibility, closer to stakeholders, quicker response time).

Goal 7 – Ensure the fiscal stability & efficient administration of the Commission

Goal 7 will ensure that the business affairs of the Commission are managed effectively and efficiently, including workload balancing through the development of annual action plans to support the Commission's management process. It also highlights the need for the Commission to efficiently manage its resources. The goal promotes the efficient use of legal advice to proactively review policies and react to litigation as necessary. It also promotes human resource policies that attract talented and committed individuals to conduct the work of the Commission. The goal highlights the need for the Commission as an organization to continually expand its skill set through training and educational opportunities. It calls for Commissioners and Commission staff to maintain and increase the institutional knowledge of the Commission through periods of transition. Achieving this goal will build core strengths, enabling the Commission to respond to increasingly difficult and complex fisheries management issues.

Strategies to Achieve Goal

7.1 Conservatively manage the Commission's operations and budgets to ensure fiscal stability.

Task 7.1.1 – Monitor and update as necessary guidelines for cost effective meeting locations and meeting attendee travel policies.

Task 7.1.2 – Responsibly manage and review as necessary the Commission's reserve fund according to the approved investment policy. Review investments annually with AOC.

Task 7.1.3 – Submit a Certification of Indirect Cost to the Department of Commerce.

Task 7.1.4 – Monitor expenditures on a monthly basis and project variances to ensure complete and timely use of available funds relative to grant cycles. Distribute monthly financial report to Senior Staff.

Task 7.1.5 – Prepare for and work cooperatively with CPA firm to conduct annual audit.

Task 7.1.6 – Update physical inventory.

Task 7.1.7 – Provide administrative support to MRIP Dockside Survey APAIS, including human resources and meeting management, grant and financial monitoring and office space.

Task 7.1.8 – Provide administrative support to NMFS At-Sea Observer Program.

Task 7.1.9 – Provide administrative support to the ACCSP, including human resource and meeting management, grant and financial monitoring and office space.

Task 7.1.10 – Continue to provide administrative support to the Atlantic Coastal Fish Habitat Partnership (ACFHP), including logistical support for committee meetings and other Partnership activities.

Subtask 7.1.10.1 – Assist in obtaining future funding to support ACFHP operations and fish habitat conservation projects.

7.2 Utilize new information technology to improve meeting and workload efficiencies, and enhance communications.

Task 7.2.1 – Attend information technology seminars/trade shows to remain abreast of current and future technologies.

Task 7.2.2 – Ensure consistency of software across the Commission and continue to cross-train administrative staff.

Task 7.2.3 – Provide targeted staff training for full use of office equipment and software.

Task 7.2.4 – Document standards for electronic record retention and develop site map of Commission electronic filing system for internal use.

Task 7.2.5 – Conduct audit of Commission databases to verify contacts and relevant information.

Task 7.2.6 – Develop link between ASMFC contacts database and website to provide up-to-date Committee lists.

Task 7.2.7 – Continue to document Standard Operating Practices and Procedures (SOPPs).

Task 7.2.8 – Continue to live stream Commission meetings and seek improvements to process.

7.3 Refine strategies to recruit professional staff, and enhance growth and learning opportunities for Commission and state personnel.

Task 7.3.1 – Promote Commission’s programs and activities and recruit new talent by conducting seminars to graduate level marine programs.

Task 7.3.2 – Provide opportunities for undergraduate and graduate students to participate in internships at the Commission.

Task 7.3.3 – Review and revise position descriptions as necessary.

Task 7.3.4 – Review vacancy announcement distribution list and update as necessary.

Task 7.3.5 – Conduct stock assessment methods training workshops. (See Task 2.5.1)

Task 7.3.6 – Conduct Commissioner workshop to enhance leadership, decision making, and strategic thinking skills.

Task 7.3.7 – Conduct meeting management training for committees chairs.

Task 7.3.8 – Facilitate staff participation at national and regional conferences; provide professional training opportunities.

Task 7.3.9 – Facilitate educational opportunities targeted to specific staff based on job responsibilities.

Task 7.3.10 – Conduct annual meeting with financial advisor to review retirement program performance with staff and provide opportunities for staff to meet individually with financial advisor to match financial goals with investment choices for retirement.

7.4 Fully engage new Commissioners in the Commission process and document institutional knowledge.

Task 7.4.1 – Work with Executive Committee to determine the appropriate transition and orientation program for new Commissioners.

Task 7.4.2 – Update and distribute, as necessary, the Commissioner Manual.

Task 7.4.3 – Continue to provide orientation materials for new members of Commission supporting committees.

Task 7.4.4 – Revise *Forging Knowledge into Change* for distribution at the Commission's 75th Annual Meeting.

7.5 Utilize legal advice on new management strategies and policies, and respond to litigation as necessary.

Task 7.5.1 – Respond as needed to litigation regarding challenges to Commission FMPs, and assist states with fisheries litigation as appropriate.

Task 7.5.2 – Work with Commission attorney to develop a potential information request policy for consideration by full Commission (FOIA equivalent).

Task 7.5.3 – Ensure annual submission of Financial Disclosure and Conflict of Interest forms by Legislative and Governor Appointee Commissioners and their proxies.

Atlantic States Marine Fisheries Commission

Atlantic Sciaenid Habitats:

A Review of Utilization, Threats, and Recommendations for Conservation, Managements, and Research Needs

CHAPTER 1: Introduction

CHAPTER 2: Atlantic Croaker

Populated with Habitat Section from Amendment 1 to the ISFMP (2005)

Section I. General Description of Habitat

Atlantic croaker was described by Petrik et al. (1999) as a habitat generalist. Field surveys of post-settlement croaker in estuarine nursery areas, found no significant differences in abundances among submerged aquatic vegetation, marsh edge, and sandy bottom (Petrik et al. 1999). In a wetland system, Atlantic croaker along the gulf coast preferred non-vegetated bottom adjacent to wetlands, rather than the marsh itself (Rozas and Zimmerman 2000). In North Carolina, Atlantic croaker have been documented to utilize SAV, wetlands, unvegetated soft bottom, and to a lesser extent, shell bottom (Street et al. 2005). Juvenile croaker utilize these habitats for refuge and foraging and as a corridor through the estuary. In North Carolina, Atlantic croaker is one of the dominant juvenile fish species in North Carolina estuaries (DMF, unpublished data). Because croaker utilizes multiple habitats, the effect of habitat change and condition on fish population is difficult to assess.

Part A. Spawning Habitat

Geographic and Temporal Patterns of Migration

Atlantic croaker spawn in tidal inlets, estuaries, and on the continental shelf, at depths ranging from 7 to 81 m (26 to 266 ft) and in polyhaline and eurohaline zones (Diaz and Onuf 1985). Exact spawning locations may be related to warm bottom waters (Miller et al. 2002). Atlantic croaker have a long spawning season that generally starts in late summer and continues to early spring, with peak reproductive activity occurring in late fall and winter (Diaz and Onuf 1985). In the Chesapeake Bay and North Carolina, spawning begins as early as August and usually peaks in October, whereas peak spawning occurs in November, in the Gulf of Mexico (USFWS 1996).

Salinity

Substrate

Temperature

Spawning is reported to occur at water temperatures of 16-25° C in North Carolina (Street et al. 2005).

Dissolved Oxygen

Feeding Behavior

Competition and Predation

Part B. Egg and Larval Habitat

Geographic and Temporal Patterns of Migration

After hatching, larvae drift into estuaries by passive and active transport via floodtides, upstream bottom currents, and other large-scale oceanographic processes. Older and larger larvae actively swim into these areas (Miglarese et al. 1982, Petrik et al. 1999). Arrival time into estuaries varies regionally. Larvae are present in the Chesapeake Bay and on the North Carolina and Virginia coasts as late as September, and as early as June on the Louisiana coast (USFWS 1996). Localized processes like currents and tidal regimes influence the dispersal of larvae to nursery areas (Petrik et al. 1999). Upon initial arrival in the estuary, larval croaker are restricted to the surface water. However during ebbing tides, larval croakers move to the brackish, bottom waters where they complete their development into juveniles (Miller 2002).

Salinity

Pelagic eggs are found in polyhaline and euryhaline waters.

Substrate

Temperature

Larvae can tolerate colder water temperatures than adults, but extremely cold temperatures may be a major source of larval mortality.

Dissolved Oxygen

Feeding Behavior

Competition and Predation

Part C. Juvenile Habitat

Geographic and Temporal Patterns

Juveniles use estuaries and tidal riverine habitats along the U.S. Atlantic coast from Massachusetts to northern Florida, and in the Gulf of Mexico, but are most common in coastal waters from New Jersey southward (Able and Fahey 1998; Robbins and Ray 1986; Diaz and Onuf 1985). Recruitment of juveniles into estuaries may be influenced by tidal fluxes in estuaries. For example, in the Pamlico Sound, North Carolina, a shallow estuary where tidal fluxes are largely controlled by wind, recruitment of juveniles is slower than the Cape Fear estuary, where tidal fluxes dictated by lunar cycles average 1.5 meters (Ross 2003). The Cape Fear estuary is representative of most drowned river valley Atlantic Coast estuaries. Juveniles remain in these habitats until early to mid-summer (USFWS 1996). Juveniles migrate downstream as they develop and by late fall, most juveniles emigrate out of the estuaries for open ocean habitats (Miglarese et al. 1982).

Salinity

Juveniles are associated with areas of stable salinity and tidal regimes and often avoid areas with large fluctuations in salinity. The upper, less saline parts of the estuaries provide the best environment for high growth and survival rates (Ross 2003, Peterson et al. 2004). Juveniles concentrate in oligohaline and mesohaline waters (0.5 to 18 ppt), although they may tolerate more extreme salinities (Diaz and Onuf 1985, Ross 2003). Ross (2003) showed that, juveniles experience reduced mortality in less saline areas. Lower mortality in the less saline areas may be because of lower physiological stress in those environments (Ross 2003). Growth rates in juveniles may be affected by fluctuating salinities and temperatures (Peterson et al. 2004; Chao and Musick 1977). Large changes in salinity can alter the activity of croakers in a way that reduces local abundance; however, smaller changes do not appear to affect juveniles. Sharp fluctuations in salinity can cause intermediate growth rates and increase the bioenergetic costs for juveniles (Peterson et al. 2004).

Able and Fahey (1997) suggested that survival in cold December waters in Delaware Bay are not conducive to survival of young croaker. Juvenile croaker prefer deeper tidal creeks because the salinity changes are usually less than in shallow flats and marsh creeks (Diaz and Onuf 1985). Salinity may affect the size distribution of juveniles within an estuary, which may be a result of changing physiological requirements as the juveniles develop (Miglarese et al. 1982).

Substrate

Substrate plays a large role in determining juvenile croaker distribution. Juveniles are positively correlated with mud bottoms with large amounts of detritus that provides sufficient prey (Cowan and Birdsong 1988). Sand and hard substrates are not suitable. Juvenile are often found in more turbid areas of estuaries with higher organic loads that provide a food source for the croakers, but low turbidity is not a limiting factor in juvenile distribution (Diaz and Onuf 1985). The latter stages of young croaker are found more commonly in grass bed in Chesapeake Bay (Olney and Boehlert 1988).

Depth

Juvenile Atlantic croaker live at a variety of depths, depending on the estuary. North Carolina estuaries and the coast of the Gulf of Mexico have small tidal fluctuations. In these areas, juvenile croakers amass in shallow, peripheral areas. In estuaries with greater tidal fluctuations such as the Delaware Bay, Chesapeake Bay, or the Cape Fear River Estuary, juvenile croaker assemble in deep channels (Diaz and Onuf 1985).

Temperature

Field and laboratory data indicate that juveniles are more tolerant of lower temperatures than adults. Juveniles have been found in waters from 0.4° C to 35.5° C (USFWS 1996) but extreme temperature changes can incapacitate juvenile croakers (Diaz and Onuf 1985). Juveniles may favor conditions that can result in low dissolved oxygen, although juveniles will move out of an area if dissolved oxygen levels decrease beyond preferred tolerances (Diaz and Onuf 1985).

Dissolved Oxygen

Feeding Behavior

In Delaware Bay, Nemerson and Able (2004) found that the largest concentrations of newly recruited Atlantic croaker were collected over soft bottom habitat having high abundance of benthic invertebrates. Annelids were an important prey component of their diet.

Competition and Predation

Part D. Adult Habitat

Geographic and Temporal Patterns of Migration

Atlantic croaker is one of the most common bottom dwelling, estuarine species on the Atlantic Coast. Atlantic croaker range from the coastal waters of Cape Cod, Massachusetts to Florida, but croaker are uncommon north of New Jersey. Croakers are also found along the Gulf of Mexico coast with high abundances in Louisiana and Mississippi (Lassuy 1983).

Salinity

Adults are found in salinity ranges from 0.2-70 ppt, but are most common in waters with salinities ranging from 6-20 ppt (Lassuy 1983, Eby and Crowder 2002). Catch of adult croakers is negatively correlated with increasing salinities (TSNL 1982), but catch also varies with season. In spring, most catch of adult Atlantic croaker is in salinity ranges from 3-9ppt, but in summer, catch peaks in two ranges: the low salinities ranging from 6-12ppt, and high salinities ranging from 24-27ppt (Miglarese et al. 1982). Generally, adults avoid the mid-salinity ranges (Miglarese et al. 1982, Peterson et al. 2004). Mean total length positively correlates with bottom salinities (Miglarese et al. 1982). Turbidity, nitrate-nitrogen concentrations, and total phosphate-phosphorous concentrations also correlate positively with croaker abundance and catch (TSNL 1982).

Substrate

Adult Atlantic croaker prefer muddy and sandy substrates in waters shallow enough to support submerged aquatic plant growth. Adults have also been collected over oyster, coral, and sponge reefs, as well as man-made structures such as bridges and piers. Adult Atlantic croaker also use Thalassia sp. beds for refuge although abundance in the seagrass beds is temperature-dependent and changes seasonally (TSNL 1982).

Temperature

Temperature and depth are strong predictors of adult croaker distribution and the interaction between the two variables may also influence distribution (Eby and Crowder 2002). Adult croaker generally spend the spring and summer in estuaries, moving offshore and to southern latitudes along the Atlantic coast in the fall. Their migration cooling water temperatures because croakers cannot survive in cold winter temperatures. Adults are found in waters from 5° C to 35.5° C, but most catch occurs in temperatures over 24° C (Miglarese et al. 1982). Generally fish over 1 year old are absent in waters below 10° C (Lassuy 1983). Optimal temperatures for growth and survival are not known (Eby and Crowder 2002).

Dissolved Oxygen

The distribution and extent of hypoxic zones in estuaries may also influence habitat use and distribution (Eby and Crowder 2002). Croaker generally shift from deep, hypoxic water to shallow, oxygenated waters during hypoxic events. Their distribution is further limited when hypoxic conditions occur in shallower waters. The lower threshold of dissolved oxygen for Atlantic croaker is about 2.0 mg/L. Below this limit, Atlantic croaker may not survive or may experience sublethal effects. Studies have shown that Atlantic croaker are virtually absent from waters with dissolved oxygen levels below 2.0 mg/L, suggesting they are very sensitive to the amount of dissolved oxygen present (Eby and Crowder 2002).

The size of a hypoxic zone influences habitat use as well. When hypoxic conditions spread in an estuary, Atlantic croaker are forced to use less suitable habitat. Atlantic croaker could incur increased physiological and ecological costs in these areas. For example, Atlantic croaker may face increased intra- and interspecific competition for available space or food in what are essentially compressed habitat zones. To avoid the increased ecological cost, the croaker may return to waters with lower dissolved oxygen (Eby and Crowder 2002).

Feeding Behavior

Competition and Predation

<u>Section II. Essential Fish Habitats and Habitat Areas of Particular Concern</u>

Essential Fish Habitat

Identification of Habitat Areas of Particular Concern

Estuaries, which are especially vulnerable to anthropogenic changes, are designated as Habitat Areas of Particular Concern (HAPCs) Atlantic croaker, as well as for other species. Larvae are particularly vulnerable to changes in estuarine conditions. Environmental conditions in spawning areas may affect growth and mortality of egg and larval croakers (Eby and Crowder 2002).

Present Condition of Habitat Areas of Particular Concern

Estuarine areas may be functionally reduced in size or degraded by numerous activities, including but not limited to, development, dredging and filling, toxic chemical and nutrient enrichment discharges from point and non-point sources, habitat alteration (e.g., wetlands converted to agricultural use), failing septic systems, and alterations in seasonal runoff patterns (S.J. Vanderkooy, Gulf States Marine Fisheries Commission, personal communication). These events may reduce the quantity and quality of Atlantic croaker habitat. Scientists believe that Atlantic croaker are affected by these changes, but few specific studies have quantified the effects of habitat degradation on the fishery resource (S.J. Vanderkooy, Gulf States Marine Fisheries Commission, personal communication).

Many coastal and estuarine areas have inadequate water quality because of various land use activities. The Chesapeake Bay is one example of an area that experiences eutrophication from agricultural runoff. Excess nutrients entering coastal waters may cause algal blooms that reduce dissolved oxygen, resulting in hypoxic or anoxic conditions, especially during the summer months (R. Lukacovic, Maryland Department of Natural Resources, personal communication). Large hypoxic areas have also been documented in Louisiana's coastal waters during the summer, because of nutrient loading into the Mississippi River from the Midwestern farm belt. These event can directly impact fisheries in the area (S.J. Vanderkooy, Gulf States Marine Fisheries Commission, personal communication).

Section III. Threats and Uncertainties

Significant Environmental, Temporal, and Spatial Factors Affecting Distribution of Atlantic Croaker

Juvenile croaker may be affected by hydrological modifications, water quality degradation, or habitat alterations. Hydrological modifications such as ditching and channelization increase the slope of the shoreline and water velocities in the altered stream. Higher water velocity and reduced natural wetland filtration can result in increased shoreline erosion, increasing sediment and non-point pollutant loading in channelized water bodies (White 1996; EPA 2001). Several studies have found that the size, number, and species diversity of fish in channelized streams are reduced and the fisheries associated with them are less productive than those associated with unchannelized reaches of streams (Tarplee et al. 1971; Hawkins 1980; Schoof 1980). Pate and Jones (1981) compared nursery areas in North Carolina that were altered and unaltered by channelization and found that Atlantic croaker and other estuarine-dependent species were more abundant in nursery habitats with no man-made drainage. They attributed this to the unstable salinity conditions that occurred in areas adjacent to channelized systems following moderate to heavy rainfall (>1 inch/24 hr).

Pollutants negatively affect growth and physical condition of juvenile Atlantic croaker, with significantly reduced growth rates and condition occurring with increasing pollutant conditions (Burke et al. 1993). Low concentrations of heavy metals can accumulate in fine-grained sediments, particularly organic-rich muddy substrates, to toxic levels, and can be resuspended into the water column (Riggs et al. 1991). Primary nursery areas in North Carolina often consist of such fine-grained sediments and are therefore susceptible to toxic contamination of bottom sediments (Street et al. 2005).

Severe hypoxia of bottom water and sediments, often associated with eutrophication, can adversely affect croaker populations through suffocation, reduced growth rates, loss of preferred benthic prey, changes in distribution, or disease (Street et al. 2005). Mass mortality of benthic infauna associated with anoxia has been documented in the deeper portions of the Neuse River estuary in North Carolina, in association with stratification of the water column in the summer (Lenihan and Peterson 1998; Luettich et al. 1999). During these events, oxygen depletion caused mass mortality of up to 90% of the dominant infauna within the affected area (Buzelli et al. 2002). Utilizing a statistical model and field data, it was estimated that the extensive benthic invertebrate mortality, resulting from intensified hypoxia events, reduced total biomass of demersal predatory fish and crabs during summer months by 17-51% in 1997-1998 (Baird et al. 2004). The decrease in available energy from reduced benthos greatly reduced the ecosystem's ability to transfer energy to higher trophic levels at the time of year most needed by juvenile fish (Baird et al. 2004).

Alteration of natural shorelines has been shown to have a negative impact on juvenile Atlantic croaker populations. In a study along the Gulf coast comparing fish abundance between unaltered and altered shorelines (bulkheads or rubble), croaker was most abundant at the unaltered unvegetated shoreline (Peterson et al. 2000). Other anthropogenic activities that can potentially degrade shallow shoreline habitat conditions include dredging and proliferation of docks and marinas (Street et al. 2005).

In spring and fall in moderate water temperatures, moderate hypoxia may not be a limiting Atlantic croaker distribution. However, in summer when water temperatures are higher Atlantic croaker may avoid moderately hypoxic zones in order to avoid the additional physiological costs of staying in waters with less dissolved oxygen (Eby and Crowder 2002). As hypoxia increases in severity and scope within estuarine waters, croaker typically move to shallower parts of an estuary. Large hypoxic zones may limit adult croaker depth and temperature distribution, suggesting a shift in habitat use driven by the severity of a hypoxic event (Eby and Crowder 2002). Atlantic croaker may actually be limited to areas with higher temperatures than their preferred temperatures during hypoxic events (Eby and Crowder 2002).

Unknowns and Uncertainties

Section IV. Recommendations for Habitat Management and Research

Habitat Management Recommendations

Each state should implement a protection plan for Atlantic croaker habitat within its jurisdiction to ensure the sustainability of the spawning stock that is produced or resides within its state boundaries. Each program should inventory the historical and present range of croaker, specify the habitats that are targeted for restoration, and impose or encourage measures to preserve the quantity and quality of Atlantic croaker habitats.

1. States should notify in writing the appropriate federal and state regulatory agencies of the locations of habitats used by Atlantic croaker for each life stage. Regulatory agencies should be advised of the types of threats to Atlantic croaker populations and recommend measures that should be employed to avoid, minimize, or eliminate any threat to current habitat quality or quality.
2. State fishery regulatory agencies, in collaboration with state water quality agencies, should monitor hypoxic conditions in state waters (including estuaries and tidal basins) and report changes in Atlantic croaker abundance or habitat use.

3. Where sufficient knowledge is available, states should designate Atlantic croaker habitat areas of particular concern for special protection. These locations should be designated High Quality Waters or Outstanding Resource Waters and should be accompanied by requirements that limit degradation of habitat, including minimization of non-point source runoff, prevention of significant increases in contaminant loadings, and prevention of the introduction of any new categories of contaminants into the area (via restrictions on National Pollutant Discharge Elimination System (NPDES) discharge permits for facilities in those areas).
4. State fishery regulatory agencies should develop protocols and schedules for providing input on water quality regulations and on Federal permits and licenses required by the Clean Water Act, Federal Power Act, and other appropriate vehicles, to ensure that Atlantic croaker habitats are protected and to ensure that specific that water quality needs for Atlantic croaker are met.
5. Water quality criteria for Atlantic croaker spawning and nursery areas should be established, or existing criteria should be upgraded, so as to ensure successful reproduction. Any action taken should be consistent with Federal Clean Water Act guidelines and specifications.
6. All State and Federal agencies responsible for reviewing impact statements and permit applications for projects or facilities proposed for croaker spawning and nursery areas should ensure that those projects will have no or only minimal impact on local stocks. Any project that would result in the elimination of essential habitat should be avoided.
7. Federal and State fishery management agencies should take steps to limit the introduction of toxic compounds known to accumulate in Atlantic croaker and that pose threats to wildlife and human health.
8. Each State should establish windows of compatibility for activities known or suspected to adversely affect Atlantic croaker life stages and their habitats. Activities may include, but are not limited to, navigational dredging, bridge construction, and dredged material disposal, and notify the appropriate construction or regulatory agencies in writing.
9. Projects involving water withdrawal from nursery habitats (e.g. power plants, irrigation, water supply projects) should be evaluated to ensure that larval or juvenile impingement or entrainment is minimized, and that any modifications to water flow or salinity regimes maintain levels within croaker tolerance limits.
10. Each state should develop water use and flow regime guidelines to ensure the appropriate water levels and salinity levels are maintained for the long-term protection and sustainability of the stock. States should work to ensure that proposed water diversions or withdrawals from rivers upstream will not reduce or eliminate conditions favorable to Atlantic croaker.
11. The use of any fishing gear that is determined by management agencies to have a negative impact on Atlantic croaker habitat should be prohibited within habitat areas of particular concern (e.g. trawling in spawning areas or primary nursery areas should be prohibited).
12. States should work to reduce the input of contaminants to Atlantic croaker habitats.
13. States should work with the U.S. Fish and Wildlife Service, Divisions of Fish and Wildlife Management Assistance and Ecological Services, and National Marine

Fisheries Service (NMFS), Offices of Fisheries Conservation and Management and Habitat Conservation, to identify hydropower dams that pose significant threats to maintenance of appropriated freshwater flows (volume and timing) to Atlantic croaker nursery and spawning areas and target these dams for appropriate recommendations during FERC re-licensing.

Habitat Research Recommendations

Although Atlantic croaker habitats have undergone loss and degradation, studies are needed to quantify the impact on Atlantic croaker populations. For example, there has been some speculation in recent years that extensive areas of low dissolved oxygen in the Chesapeake Bay killed most of the benthic organisms in the deeper water where croaker feed. Unfortunately, no research has been conducted to confirm the impact of hypoxia on food resources in this region (R. Lukacovic, Maryland Department of Natural Resources, personal communication).

The early life history of the Atlantic croaker is not well documented, yet events during this phase could have a significant impact on recruitment. A better understanding of this life stage of the species is needed to identify its habitat requirements, allowing scientists to evaluate the relative impacts of natural and anthropogenic disturbances.

Periodic review of various programs to monitor habitat and water quality could play an important role in understanding red drum population dynamics. The following topics should be examined: nutrient loading; long-term water quality monitoring; hypoxia events; incidence of red tides, harmful dinoflagellates and *Pfisteria*; habitat modification permits; and wetlands protection.

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CHAPTER 3: Black Drum

Updated research for life stages.

EFH, HAPC, and Threats are populated with Habitat Section from the Interstate Fishery Management Plan for Black Drum
Some of the black drum habitat sections were adapted from red drum's habitat needs.

Section I. General Description of Habitat

Black drum in the Atlantic form one population, with two separate populations existing in the Gulf of Mexico (Gold and Richardson 1998). Like many coastal species, oceanic spawning is followed by ingress of eggs and larvae to mid and upper estuarine habitats, although substantial variation likely exists with respect to settlement. Juvenile black drum are largely estuarine-dependent, but throughout the first year of life begin moving to the lower estuary and possibly into the coastal ocean by the fall of year one (Able and Fahay 2010). Geographic adult age structure has been suggested, with older individuals more common in the mid-Atlantic Bight than in the South Atlantic Bight, although a general movement pattern has been described as north and inshore in the spring, and south and offshore in the fall, which may confound true patterns of habitat use.

Part A. Spawning Habitat

Geographic and Temporal Patterns of Migration

In the Atlantic basin, black drum spawn from April to June in the northern range (Joseph et al. 1964; Richards 1973; Silverman 1979). In the Mid-Atlantic region, spawning in the mouth of the Chesapeake Bay and larger estuaries has been well documented (Able and Fahay 2010) and the presence of a large spring/early summer fishery on spawning fish in the Delaware Bay also supports evidence of spawning occurring inshore and in the spring. Studies in Florida suggests spawning occurs in deep waters inshore, from November through April, with peaks in February and March (Murphy and Taylor 1989). It is noteworthy that the drumming sound made by black drum is associated with spawning behaviors, and several studies have measured noise in an effort to describe reproduction (in the Gulf of Mexico Saucier and Baltz 1993 and Locascio and Mann 2011; in South America Tellechea et al. 2010).

Fitzhugh et al. (1993; but on Gulf of Mexico black drum) noted a difference in sex ratios in Louisiana during the spawning season between fish caught offshore by trawls (dominated by males), and fish caught inshore by gillnet and haul-seines (dominated by females). These skewed sex ratios were not found before or after the spawning period. The authors concluded the catches reflected a true segregation of the sexes during the spawning period, suggesting the use of different habitats.

Salinity

Commented [SM1]: Maybe a footnote or some other designation to convey the fact that all this spawning habitat work comes from 2 relatively small spawning studies in the Gulf of Mexico. They are actually really cool studies that focus on the acoustics of spawning, but they measured a lot of environmental data. So while I would tend to trust the studies, I worry about their ability to generalize in describing what goes in black drum spawning in the Chesapeake or Delaware Bays, for example.

Salinity during drumming aggregations has been reported to range from 18.8–20.8 ppt in Louisiana (Saucier and Baltz 1993). Based on coastal ocean and lower estuary reported spawning habitats, euryhaline or full seawater salinities would be expected.

Substrate

None of the spawning studies describe substrate in association with a particular spawning aggregation; however, Saucier and Baltz (1993) generally describe the study sites to be heterogeneous, and include slit, clay, mud, sand, and detritus, and Locascio and Mann (2011) describe their sites as soft muddy composite.

Temperature

From studies limited to the Gulf of Mexico, spawning aggregations have been associated with temperatures ranging from 18–22°C (Locascio and Mann 2011) and with means of 18.8°C (for large drumming aggregations) and 20.8°C (for moderate drumming aggregations; Saucier and Baltz 1993).

Dissolved Oxygen

Saucier and Baltz (1993) present the only dissolved oxygen data associated with black drum spawning. They report means of 12.3 and 11.6 mg/L for large and moderate spawning aggregations, respectively. Inference on DO preference or tolerance ranges (or in other spatial spawning aggregations) should be approached cautiously.

Feeding Behavior

No published work has reported on the feeding behaviors of spawning individuals. It might be inferred—based on nearshore and estuarine habitats—that spawning black drum feed on the same food sources as adults, which includes primarily crustaceans and mollusks.

Competition and Predation

Competition among black drum and with other species is undocumented for spawning adults. Because spawning habitat is not yet described at a fine scale (microhabitat), it is unclear whether spawning habitats are limiting, and if competition exists for these habitats or inclusion in spawning aggregations. Predation of spawning adults is likely similar to adult *P. cromis*, although possibly depressed from both lower predatory metabolic demands from cooler winter and spring water temperatures, and the absence of many estuarine shark species until late spring (Ulrich et al. 2007).

Part B. Egg Habitat

Geographic and Temporal Patterns of Migration

Along the Atlantic coast, black drum eggs are spawned during the spring, from April to June in the northern range (Joseph et al. 1964; Richards 1973; Silverman 1979), and in February and March in the southern range (data from Florida; Murphy and Taylor 1989). Most spawning has been reported or estimated to take place nearshore in the coastal ocean, though some eggs have been sampled in the lower reaches of larger estuaries, such as the Chesapeake Bay (Daniel and Graves 1994). Spawning takes place when temperatures are between 17.5 and 19°C (Joseph et al.

1964; Richards 1973). Black drum eggs are pelagic, and at 20°C hatch in less than 24 hours (Joseph et al. 1964). Some migration from tidal stream transport many take place; however, due to the short duration of the egg stage it is unlikely that much distance is covered.

Salinity

Although not being spawned offshore, black drum eggs in the coastal ocean are assumed to be exposed to full seawater (35 ppt) or at least polyhaline conditions for their brief duration as an egg.

Substrate

Because the egg stage of black drum eggs occurs entirely offshore and the eggs are positively buoyant in order to use sea surface or tidal transport to move them toward coastal areas, substrate is not considered a critical aspect of black drum egg habitat.

Temperature

Spawning has been reported to take place when temperatures are between 17.5 and 19°C (Joseph et al. 1964; Richards 1973), and thus optimal (or tolerated) egg temperatures are likely very similar.

Dissolved Oxygen

Because the egg stage of black drum occurs entirely offshore, eggs are likely only ever exposed to normoxic waters (>5 mg/L). It is not currently thought that dissolved oxygen is a limiting factor to survival of black drum eggs.

Feeding Behavior

Black drum eggs subsist entirely off the yolk sac prior to hatch.

Competition and Predation

Black drum eggs likely do not enter into any meaningful ecological competition, as their habitat demands are basic (and largely met by the oceanic or estuarine conditions). Predation of eggs undoubtedly occurs by a variety of oceanic and estuarine consumers. Specifically, Cowan et al. (1992) reported predation of black drum eggs by ctenophores and hydromedusae in the Chesapeake Bay with potentially very high levels of predation during years where both gelatinous predators have high abundances.

Part C. Larval Habitat

Geographic and Temporal Patterns of Migration

Black drum larvae hatch around 2.5 mm (Able and Fahay 2010) and ingress from nearshore and lower estuarine egg habitats using tidal stream transport to variable locations within estuaries. Overall the general pattern documented is for larvae to move from higher salinity areas to lower salinity estuarine habitats (from otolith microchemical analyses; Rooker et al. 2004), and Gold and Richardson (1998) used molecular methods to characterize black drum as estuarine-dependent in the early years. However, black drum may be less dependent on upper, oligohaline and mesohaline estuarine habitats as larvae have been collected in higher salinities of 21 ppt (but in Gulf of Mexico; Peters and McMichael 1990). As with other sciaenids, it is likely that larval black drum settle in a range of estuarine habitats with confounding of estuarine-specific habitat availabilities and true preferences obscuring a distribution-wide pattern.

Salinity

Peters and McMichael (1990) collected larvae off the Gulf Coast of Florida in salinities ranging from 21 to 31 ppt. The larval stage of black drum likely uses the lowest salinity habitats of any life stage, although there are few records of larvae collected in low salinity, upper estuarine habitats.

Substrate

Peters and McMichael (1990) collected larvae off the Gulf Coast of Florida over a variety of substrates, including sand, mud, and shells. Larval collections in the Atlantic, particularly with respect to substrate, are poorly known.

Temperature

Peters and McMichael (1990) collected larvae off the Gulf Coast of Florida in water temperatures ranging from 21.9 to 24.6.

Dissolved Oxygen

Dissolved oxygen demands are likely met offshore, as well as inshore after ingress. Both of these habitats typically do not experience hypoxic conditions in the winter and spring, although no published studies have reported on any limitations.

Feeding Behavior

Like most larval fish, black drum feed on their yolk sac initially (up to 4 days, or to an estimated 2.8 mm; Joseph et al. 1964). Post-yolk sac larvae then begin to feed generally on zooplankton (Benson 1982), and more specifically copepods (Peters and McMichael 1990).

Competition and Predation

Black drum larvae may experience density dependence, although this phenomenon has not been documented and the variety of settlement habitats may release them from specific habitat or spatial constraints. Additionally, the species' relatively long spawning season may mitigate against a temporal bottleneck for habitat. Larval black drum are likely subject to predation by a range of estuarine predators; however, particular attention has been paid to hydromedusa and ctenphore predation, which has been hypothesized to impact recruitment in years of low black drum production and high densities of hydrozoans (Cowan et al. 1992).

Part D. Juvenile Habitat

Geographic and Temporal Patterns of Migration

Broadly, juvenile black drum likely use a range of estuarine habitats. Small juveniles have been documented in upper and middle parts of estuaries, where salinities are low (<6 ppt; Able and Fahay 2010). However, by the summer months, juveniles begin moving down in the estuary into tidal and marsh habitats and are not found in rivers. By the fall, some juveniles are even found in ocean habitats. Beach seine sampling in Florida nearshore lagoons found high levels of juveniles, indicating juvenile black drum remain inshore (Peters and McMichael 1990).

Salinity

Salinity exposure is likely variable both across a cohort as well as the individual level. Some juveniles have been sampled in lower estuary, high salinity (>30 ppt) locations (Peters and McMichael 1990), while others have reported juvenile black drum in freshwater (Thomas and Smith 1973). Some reports have discussed a size effect to down-estuary movement, in which migrations to lower estuary or ocean habitats is influenced by size, and which might help explain the ubiquitous distribution of juvenile black drum in estuaries. To some degree, size is likely an effect of down-estuary migration as it fits with the overall pattern of habitat use; however, finer scales of size impacts are not well documented and may vary by estuary, year, or other factors.

Substrate

Peters and McMichael (1990) reported juvenile black drum over over unvegetated mud bottoms, and Pearson (1929) reported muddy, estuarine bottoms as the most common juvenile substrate. However, as with salinity, juveniles likely use a range of habitats and substrates.

Temperature

Juvenile *P. cromis* likely experience a range of temperatures throughout their first year in an estuary. Juveniles in the Gulf of Mexico primarily sampled over summer and fall months were captured at 20.8–26.3°C (Peters and McMichael 1990). Winter temperature drops are common causes of estuarine fish kills, and black drum are vulnerable to this condition (Simmons and Breuer 1962); McEachron et al. (1994) noted black drum in several winter kills in Texas coastal waters, though the length data presented suggests many of these fish were adults and not juveniles.

Dissolved Oxygen

Currently, there is no known information on juvenile black drum sensitivity to dissolved oxygen levels.

Feeding Behavior

Small juveniles primarily feed on amphipods, mollusks, polychaetes, and small fish (Peters and McMichael 1990). As juveniles grow, Peters and McMichael (1990) found their consumption of shrimp, crabs, fish, and mollusks became more dominant, with the crossover correlating with the development of pharyngeal molars.

Competition and Predation

Based on the within-estuary movement during the first year of life and wide use of estuarine resources, little is reported on competition among black drum or with other estuarine species. Pharyngeal teeth permit black drum to eat a wide variety of mollusks and other prey items, which may limit competition on a single food source (Sutter et al. 1986). Predation of juvenile black drum likely takes place by estuarine predators, such as sharks, although specifics have not been reported.

Part E. Adult Habitat

Geographic and Temporal Patterns of Migration

While adult black drum likely move between estuarine and neashore habitats, multiple investigators have noted two trends. The first trend is the expected movement toward deeper waters with age (i.e., out of tidal creeks and into lower estuaries). The second geographic pattern involves general adult movements north and inshore during spring, and south and offshore during fall (Richards 1973; Murphy and Taylor 1989). Jones and Wells (2001) note the possibility of age separation, with greater proportions of older fish north of Cape Hatteras, North Carolina. However, it is unclear what proportion of the entire Atlantic population undergoes migration or whether they are influenced by factors other than spawning. Even the literature has been inconsistent with regard to how to characterize adult habitat use. For example, Sutter (1986; citing Hoese and Moore 1977) state that adult black drum are predominantly estuarine, while many other studies refer to an ocean residency period. Given the long lifespan of black drum (>50 years) and factors driving adult habitat use (e.g., spawning migration, general seasonality), it is likely that they use a variety of inshore and nearshore habitats.

Salinity

Lower estuary and coastal ocean environments in which adult black drum inhabit are likely polyhaline or full seawater, although no studies on adult salinity preference or tolerance have been reported.

Substrate

Adults likely use a wide variety of habitats and substrates, and Sutter (1986) suggests that adults are most common over sand and soft bottoms where oysters and clams can be found.

Temperature

McIlwain (1978; in Sutter 1986) reported black drum adults in a range of temperatures consisting of 12–33°C, although the true range may be wider based on the variety of habitats used by adults. The range reported here may be interpreted as a suitable range, and more extreme temperatures may be tolerated.

Dissolved Oxygen

No studies have reported on dissolved oxygen requirements for black drum, though there is little reason to suspect that adults experience sustained periods of limited dissolved oxygen. Both their mobility and range of habitats suggest that they are not constrained to or by specific, low oxygen environments.

Feeding Behavior

Adult black drum continue their predation on benthic crustaceans and mollusks, although Ackerman (1951) reported surface feeding on menhaden. Blasina et al. (2010) reported on black drum in Argentina and also found crustaceans and mollusks to dominate the diet. With efforts underway to rehabilitate Atlantic oysters, some have looked into the ability of black drum to depress recovering oyster populations (Brown et al. 2008).

Competition and Predation

Competition among black drum is likely minimal as there are no suspected habitat or forage limitations regularly imposed on adults. Adult black drum, based on their large size, are unlikely to be common prey items, but have been documented to be preyed upon by sharks (Murphy and Muller 1995).

Section II. Essential Fish Habitats and Habitat Areas of Particular Concern

Essential Fish Habitat

This section in the FMP is adapted from the Amendment 2 to the Red Drum FMP

Prior to transfer of management authority for red drum from the South Atlantic Fishery Management Council (SAFMC) to ASMFC, the SAFMC reviewed the Essential Fish Habitat (EFH) and HAPC designations for red drum. The SAFMC concluded the EFH and HAPCs would still be protected, as similar areas had been designated for other federally managed species. As a result, these areas, which serve an important role in the black drum life cycle, have retained protection and are referenced here and in the Amendment 2 to the Red Drum FMP (ASMFC 2002).

The designated EFH includes tidal freshwater, estuarine emergent vegetated wetlands (flooded salt marsh, brackish marsh, and tidal creeks), estuarine scrub/shrub (mangrove fringe), submerged rooted vascular plants (seagrass), oyster reefs and shell banks, unconsolidated bottom (soft sediment), ocean high salinity surf zones, and artificial reefs (SAFMC 1998). The area covered ranges from Virginia through the Florida Keys, to a depth of 50 m offshore.

Identification of Habitat Areas of Particular Concern

This section in the FMP was adapted from the Amendment 2 to the Red Drum FMP

Habitat Areas of Particular Concern (HAPCs) are defined by the Atlantic States Marine Fisheries Commission (ASMFC) as areas within the species habitat which satisfy one or more of the following criteria: (1) provide important ecological function, (2) are sensitive to human-induced environmental degradation, (3) are susceptible to coastal development activities, or (4) are considered to be rarer than other habitat types. For black drum, this includes the following habitats: tidal freshwater, estuarine emergent vegetated wetlands (flooded salt marshes, brackish marsh, and tidal creeks), estuarine scrub/shrub (mangrove fringe), submerged rooted vascular plants (sea grasses), oyster reefs and shell banks, unconsolidated bottom (soft sediments), ocean high salinity surf zones, and artificial reefs. These areas overlap with the designated HAPCs for red drum, designated in Amendment 2 to the Red Drum FMP (ASMFC 2002). These HAPCs include all coastal inlets, all state-designated nursery habitats (i.e. Primary Nursery Areas in North Carolina), sites where spawning aggregations of red drum have been documented and spawning sites yet to be identified, areas supporting submerged aquatic vegetation, as well as barrier islands off the South Atlantic states as they maintain the estuarine environment in which young black drum develop.

A species' primary nursery areas are indisputably essential to its continuing existence. Primary nursery areas for black drum can be found in estuaries, such as coastal marshes, shallow tidal creeks, bays, tidal flats of varying substrate, tidal impoundments, and seagrass beds. Since young black drum move among these varying environments, it is difficult to designate specific areas as deserving more protection than others. Moreover, these areas are not only primary nursery areas for black drum, but they fulfill the same role for numerous other resident and estuarine-dependent species of fish and invertebrates.

Similarly, juvenile black drum habitat extends over a broad geographic range and adheres to the criteria that define HAPCs. Juvenile black drum are found throughout tidal creeks and channels of southeastern estuaries, in backwater areas behind barrier islands and in the front beaches during certain times of the year. It is during this period that juveniles begin moving between low and higher salinity areas (Rooker et al. 2004). Therefore, the estuarine system as a whole, from the lower salinity reaches of rivers to the mouth of inlets, is vital to the continuing existence of this species.

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Commented [SM2]: So basically all habitats throughout the species' range?

Section II. Threats and Uncertainties

Significant Environmental, Temporal, and Spatial Factors Affecting Distribution of [Species]

Threats to black drum habitats include the following: loss of estuarine and marine wetlands; coastal development; nutrient enrichment of estuarine waters; poor water quality; hydrologic modifications; alteration of freshwater flows into estuarine waters.

The following section is adapted from the Amendment 2 to the Red Drum FMP

Present Condition of Habitat Areas of Particular Concern

Coastal Spawning Habitat: Condition and Threats Coastal Spawning

It is reasonable to assume that areas where coastal development is taking place rapidly, habitat quality may be compromised. Coastal development is a continuous process in all states and all coastal areas in the nation are experiencing significant growth. The following section describes particular threats to the nearshore habitats in the South Atlantic that meet the characteristics of suitable spawning habitat for black drum.

One threat to the spawning habitat for black drum is navigation and related activities such as dredging and hazards associated with ports and marinas (ASMFC, 2013). According to the SAFMC (1998), impacts from navigation related activities on habitat include direct removal/burial of organisms from dredging and disposal of dredged material, effects due to turbidity and siltation; release of contaminants and uptake of nutrients, metals and organics; release of oxygen-consuming substances, noise disturbance, and alteration of the hydrodynamic regime and physical characteristics of the habitat. All of these impacts have the potential to substantially decrease the quality and extent of black drum spawning habitat.

Besides creating the need for dredging operations that directly and indirectly affect spawning habitat for black drum, ports also present the potential for spills of hazardous materials. The cargo that arrives and departs from ports includes highly toxic chemicals and petroleum products. Although spills are rare, constant concern exists since huge expanses of productive estuarine and nearshore habitat are at stake. Additional concerns related to navigation and port utilization are discharge of marine debris, garbage and organic waste into coastal waters.

Maintenance and stabilization of coastal inlets is of concern in certain areas of the southeast. Studies have implicated jetty construction to alterations in hydrodynamic regimes thus affecting the transport of larvae of estuarine-dependent organisms through inlets (Miller *et al*. 1984; Miller 1988).

Estuarine Nursery, Juvenile and Subadult Habitat: Condition and threats

Coastal wetlands and their adjacent estuarine waters constitute primary nursery, juvenile and sub-adult habitat for black drum along the coast. Between 1986 and 1997, estuarine and marine wetlands nationwide experienced an estimated net loss of 10,400 acres. However, the rate of loss was reduced over 82% since the previous decade (Dahl 2000). Most of the wetland loss resulted from urban and rural activities and the conversion of wetlands for other uses. Along the southeast Atlantic coast, the state of Florida experienced the greatest loss of coastal wetlands due to urban or rural development (Dahl 2000). However, the loss of estuarine wetlands in the southeast has been relatively low over the past decade although there is some evidence that invasion by exotic species, such as Brazilian pepper (*Schinus terebinthifolius*), in some areas could pose potential threats to fish and wildlife populations in the future (T. Dahl, pers. comm.).

Throughout the coast, the condition of estuarine habitat varies according to location and the level of urbanization. In general, it can be expected that estuarine habitat adjacent to highly developed areas will exhibit poorer environmental quality than more distant areas. Hence, environmental quality concerns are best summarized on a watershed level.

Threats to estuarine habitats of the southeast were described in Amendment 2 to the Red Drum FMP (ASMFC 2002). Due to the black drum's dependence on estuarine habitats throughout its early years, these same threats are likely to impact black as well as red drum.

Nutrient enrichment of estuarine waters throughout the southeast is a major threat to the quality of estuarine habitat. Forestry practices contribute significantly to nutrient enrichment in the southeast. Areas involved are extensive and many are in proximity to estuaries. Urban and suburban developments are perhaps the most immediate threat to black drum habitat in the southeast. The almost continuous expansion of ports and marinas in the South Atlantic poses a threat to aquatic and upland habitats. Certain navigation-related activities are not as conspicuous as port terminal construction but have the potential to significantly impact the estuarine habitat upon which black drum depend. Activities related to watercraft operation and support pose numerous threats including discharge of pollutants from boats and runoff from impervious surfaces, contaminants generated in the course of boat maintenance, intensification of existing poor water quality conditions, and the alteration or destruction of wetlands, shellfish and other bottom communities for the construction of marinas and other related infrastructure.

Estuarine habitats of the southeast can be negatively impacted by hydrologic modifications. The latter include activities related to aquaculture, mosquito control, wildlife management, flood control, agriculture and silviculture. Also, ditching, diking, draining and impounding activities associated with industrial, urban and suburban development qualify as hydrologic modifications that may impact the estuarine habitat. Alteration of freshwater flows into estuarine areas may change temperature, salinity and nutrient regimes as well as alter wetland coverage. Studies have demonstrated that changes in salinity and temperature can have profound effects in estuarine fishes (Serafy *et al*. 1997) and that salinity partly dictates the distribution and abundance of estuarine organisms (Holland *et al*. 1996). Hence, black drum are probably as susceptible as any other estuarine organism to such changes in the physical regime of their environment.

Adult Habitat: Condition and Threats

Threats to the black drum's adult habitat are not as numerous as those faced by postlarvae, juveniles and subadults in the estuary and coastal waters. Current threats to the nearshore and offshore habitats that adult black drum utilize in the South Atlantic include navigation and related activities, dumping of dredged material, mining for sand and minerals, oil and gas exploration, offshore wind facilities, and commercial and industrial activities (SAFMC 1998).

An immediate threat is the sand mining for beach nourishment projects. Associated threats include burial of bottoms near the mine site or near disposal sites, release of contaminants directly or indirectly associated with mining (i.e. mining equipment and materials), increase in turbidity to harmful levels, and hydrologic alterations that could result in diminished desirable habitat.

Offshore mining for minerals may pose a threat to black drum habitat in the future. Currently, there are no mineral mining activities taking place in the South Atlantic. However, various proposals to open up additional areas off the Atlantic coast to seabed mining have been introduced by the Federal Executive and Legislative branches.

Offshore wind farms may also pose a threat to black drum habitat throughout different life stages in the future (ASMFC, 2012). Currently, there are no offshore wind farms established in the United States. However, the Atlantic coast is a potential candidate for future wind farm sites.

Unknowns and Uncertainties

Section IV. Recommendations for Habitat Management and Research

Habitat Management Recommendations

Particular attention should be directed toward black drum habitat utilization and habitat condition (environmental parameters). A list of existing state and federal programs generating environmental data such as sediment characterization, contaminant analysis, and habitat coverage (marsh grass, oyster beds, submerged aquatic vegetation) should also be produced and updated as new information arises. Habitats utilized by black drum range from the freshwater dividing line out to and likely beyond, the shelf break. Thus, virtually any study generating environmental data from estuarine or coastal ocean systems could be of value.

1. Where sufficient knowledge is available, states should designate black drum habitat areas of particular concern for special protection. These locations should be accompanied by requirements that limit degradation of habitat, including minimization of non-point source and specifically storm water runoff, prevention of significant increases in contaminant loadings, and prevention of the introduction of any new categories of contaminants into the area.
2. Where habitat areas have already been identified and protected, states should ensure continued protection of these areas by notifying and working with other federal, state, and local agencies. States should advise these agencies of the types of threats to black drum and recommend measures that should be employed to avoid, minimize, or eliminate any threat to current habitat quality or quantity.
3. States should minimize loss of wetlands to shoreline stabilization by using the best available information, incorporating erosion rates, and promoting incentives for use of alternatives to vertical shoreline stabilization measures, commonly referred to as living shorelines projects.
4. All State and Federal agencies responsible for reviewing impact statements and permit applications for projects or facilities proposed for black drum spawning and nursery areas should ensure that those projects will have no or only minimal impact on local stocks. Any project that would result in the elimination of essential habitat should be avoided, if possible, or at a minimum, adequately mitigated.
5. Each State should establish windows of compatibility for activities known or suspected to adversely affect black drum life stages and their habitats. Activities may include, but are not limited to, navigational dredging, bridge construction, and dredged material disposal, and notify the appropriate construction or regulatory agencies in writing.
6. Each state should develop water use and flow regime guidelines, where applicable, to ensure that appropriate water levels and salinity levels are maintained for the long-term protection and sustainability of the stocks. Projects involving water withdrawal

or interrupt water flow should be evaluated to ensure that any impacts are minimized, and that any modifications to water flow or salinity regimes maintain levels within black drum tolerance limits.

7. The use of any fishing gear that is determined by management agencies to have a negative impact on black drum habitat should be prohibited within habitat areas of particular concern. Further, states should protect vulnerable habitat from other types of non-fishing disturbance as well.
8. States should work with the U.S. Fish and Wildlife Service's Divisions of Fish and Wildlife Management Assistance and Ecological Services, and National Marine Fisheries Service's Offices of Fisheries Conservation and Management and Habitat Conservation, to identify hydropower and water control structures that pose significant threats to maintenance of appropriate freshwater flows (volume and timing) to black drum nursery and spawning areas and target these dams for appropriate recommendations during FERC re-licensing.
9. States should conduct research to evaluate the role of submerged aquatic vegetation (SAV) and other submersed structures in the spawning success, survival, growth and abundance of black drum. This research could include regular mapping of the bottom habitat in identified areas of concern, as well as systematic mapping of this habitat where it occurs in estuarine and marine waters of the states.
10. States should continue support for habitat restoration projects, including oyster shell recycling and oyster hatchery programs as well as seagrass restoration, to provide areas of enhanced or restored bottom habitat.
11. Water quality criteria for black drum spawning and nursery areas should be established, or existing criteria should be upgraded, to ensure successful reproduction of these species. Any action taken should be consistent with Federal Clean Water Act guidelines and specifications.
12. State fishery regulatory agencies, in collaboration with state water quality agencies, should monitor water quality in known habitat for black drum, including turbidity, nutrient levels, and dissolved oxygen.
13. States should work to reduce point-source pollution from wastewater through such methods as improved inspections of wastewater treatment facilities and improved maintenance of collection infrastructure.
14. States should develop protocols and schedules for providing input on water quality regulations and on Federal permits and licenses required by the Clean Water Act, Federal Power Act, and other appropriate vehicles, to ensure that black drum habitats are protected and water quality needs are met.

Habitat Research Recommendations

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Spot

CHAPTER 4: Red Drum

Populated with text from the Red Drum Habitat Addendum (2013)

Section I. General Description of Habitat

Part A. Spawning Habitat

Red drum (*Sciaenops ocellatus*) spawn from late summer to early fall in a range of habitats, including estuaries, near inlets, passes, and near bay mouths as opposed to further offshore or inland habitats (Peters and McMichael 1987). Earlier studies have illustrated that the spawning often occurred in nearshore areas relative to inlets and passes (Pearson 1929; Miles 1950; Simmons and Breuer 1962; Yokel 1966; Jannke 1971; Setzler 1977; Music and Pafford 1984; Holt *et al.* 1985). More recent evidence, however, suggests that in addition to nearshore vicinity habitats, red drum also utilize high-salinity estuarine areas along the coast (Murphy and Taylor 1990; Johnson and Funicelli 1991; Nicholson and Jordan 1994; Woodward 1994; Luczkovich *et al.* 1999; Beckwith *et al.* 2006).

Geographic and Temporal Patterns of Migration

Salinity

Coastal estuarine areas that have high salinity levels provide optimal conditions for eggs and larval development, as well as circulation patterns beneficial to transporting larvae to suitable nursery areas (Ross and Stevens 1992).

Substrate

Temperature

Spawning in laboratory studies have also appeared to be temperature dependent, occurring in a range from 22° to 30° C but with optimal conditions between temperatures of 22° to 25° C (Holt *et al.*1981). Renkas (2010) was able to duplicate environmental conditions of naturally spawning red drum from Charleston Harbor, SC in a mariculture setting, and corroborated that active egg release occurred as water temperature dropped from a peak of ~30^{o} C during August. Cessation of successful egg release was found at 25^{o} C, with no spawning effort found at lower temperatures (Renkas 2010). Pelagic eggs, embryos, and larvae are transported by currents into nursery habitats for egg and larval stages, expectedly due to higher productivity levels in those environments (Peters and McMichael 1987; Beck *et al.* 2001).

Dissolved Oxygen

Feeding Behavior

Competition and Predation

Part B. Egg and Larval Habitat

Nelson et al. (1991) reported red drum eggs to be commonly encountered in several southeastern estuaries, in salinities above 25 ppt. Indeed, laboratory experiments in Texas (Neill 1987; Holt et al. 1981) established that optimum temperature and salinity for hatching and survival of red drum larvae are 25° C and 30 ppt, respectively. The spatial distribution and relative abundance of eggs in estuaries, as expected, mirrors that of spawning adults (Nelson et. al. 1991) and eggs and early larvae utilize high salinity waters inside inlets and passes and in the estuary proper. In Florida, Johnson and Funicelli (1991) collected viable red drum eggs in Mosquito Lagoon, Florida, in average daily water temperatures of 20-25° C and average salinities of 30-32 ppt. The largest number of eggs collected during the study was in depths ranging from 1.5 to 2.1 m and highest concentrations of eggs were found at the edge of the channel.

Geographic and Temporal Patterns of Migration

Upon hatching, red drum larvae are pelagic (Johnson 1978) and evidence from laboratory studies indicates that development is temperature-dependent (Holt et al. 1981). They make the transition between pelagic and demersal habitats upon reaching the nursery grounds (Pearson 1929; Peters and McMichael 1987; Comyns et al 1991; Rooker and Holt 1997). Then they may utilize tidal currents (Setzler 1977; Holt et al. 1989) or density-driven currents (Mansueti 1960) to attain low-salinity nurseries in the upper reaches of estuaries (Mansueti 1960; Bass and Avault 1975; Setzler 1977; Weinstein 1979; Holt et al. 1983b; Holt et al. 1989; Peters and McMichael 1987; McGovern 1986; Daniel 1988). Once in the nurseries, red drum larvae grow rapidly and evidence suggests that red drum may select nursery areas based on the presence of environmental conditions that contribute to rapid growth (Baltz et al 1998).

Red drum larvae along the Atlantic coast are reportedly common in most major southeastern estuaries, with the exception of Albemarle Sound, and they are abundant in the St. Johns and Indian River estuaries, Florida (Nelson et al. 1991). Data on the spatial distribution of red drum larvae in the Gulf of Mexico has been summarized by Mercer (1984)

More recently, Lyczkowski-Shultz and Steen (1991) reported evidence of diel vertical stratification among red drum larvae found in depths < 25 m at both offshore and nearshore locations. Larvae (1.7-5.0 mm mean length) were found at depth during the night and higher in the water column during the day. At the time of this study, water was well mixed and temperature ranged between approximately 26-28° C. No consistent relationship between the distribution of larvae and tidal stage was detected.

Research conducted in Mosquito Lagoon, Florida, by Johnson and Funicelli (1991) found viable red drum eggs being collected in average daily water temperatures from 20° C to 25° C and average salinities from 30 to 32 ppt. During the experiment, the highest numbers of eggs were gathered in depths ranging from 1.5 to 2.1 m and the highest concentration of eggs was collected at the edge of the channel.

Salinity

Red drum eggs have been commonly encountered in several southeastern estuaries in high salinity, above 25 ppt (Nelson *et al.* 1991). Salinities above 25 ppt allow red drum eggs to float while lower salinities cause eggs to sink (Holt *et al.* 1981).

Spatial distribution and relative abundance of eggs in estuaries, as expected, mirrors that of spawning adults (Nelson *et al.* 1991); eggs and early larvae utilize high salinity waters inside inlets, passes, and in the estuary proper.

Substrate

Upon hatching, red drum larvae are pelagic (Johnson 1978) and laboratory evidence indicates that development is temperature-dependent (Holt *et al.* 1981). Newly hatched red drum spend around twenty days in the water column before becoming demersal (Rooker *et al.* 1999; FWCC 2008). However, Daniel (1988) found much younger larvae already settled in the Charleston Harbor estuary. Transitions are made between pelagic and demersal habitats once settling in the nursery grounds (Pearson 1929; Peters and McMichael 1987; Comyns *et al.* 1991; Rooker and Holt 1997). Tidal currents (Setzler 1977; Holt *et al.* 1989) or density-driven currents (Mansueti 1960) may be utilized in order to reach a lower salinity nursery in upper areas of estuaries (Mansueti 1960; Bass and Avault 1975; Setzler 1977; Weinstein 1979; Holt *et al.* 1983; Holt *et al.* 1989; Peters and McMichael 1987; McGovern 1986; Daniel 1988). Once inhabiting lower salinity nurseries in upper areas of estuaries, red drum larvae grow rapidly, dependent on present environmental conditions (Baltz *et al.* 1998).

Red drum larvae along the Atlantic coast are reportedly common in southeastern estuaries, with the exception of Albemarle Sound, and are abundant in the St. Johns and Indian River estuaries in Florida (Nelson *et al.* 1991). Daniel (1988) and Wenner *et al.* (1990) found newly recruited larvae and juveniles through the Charleston harbor estuary over a wide salintity range. Mercer (1984) has also summarized spatial distribution of red drum larvae in the Gulf of Mexico. More recent studies conducted by Lyczkowski-Shutlz and Steen (1991) reported evidence of diel vertical stratification among red drum larvae found at lower depths less than 25 m at both offshore and nearshore locations. Larvae (ranging between 1.7 to 5.0 mm mean length) were found at lower depths during night and higher in the water column during the day. At the time of the study, water was well mixed and temperature ranged between 26° C to 28° C. There was no consistent relationship between distribution of larvae and tidal stage. Survival during larval (and juvenile) stages in marine fish, such as the red drum, has been identified as a critical bottleneck determining their survival and contribution to adult populations (Cushing 1975; Houde 1987; Rooker *et al.* 1999).

Temperature

In Texas, laboratory experiments conducted by Neill (1987) and Holt *et al.* (1981) concluded that an optimum temperature and salinity for the hatching and survival of red drum eggs and larvae was 25° C and 30 ppt.

Spot

Dissolved Oxygen

Feeding Behavior

Competition and Predation

Part C. Juvenile Habitat

Juvenile red drum utilize a variety of inshore habitats throughout their range including tidal freshwater habitats, low-salinity reaches of estuaries, estuarine emergent vegetated wetlands, estuarine scrub/shrub, submerged aquatic vegetation, oyster reefs, shell banks, and unconsolidated bottom (SAFMC 1998b). In general, juvenile red drum are found throughout southeastern estuaries in all the habitat types described above.

Geographic and Temporal Patterns of Migration

Estuarine distribution of juvenile red drum varies seasonally as the fish grow and begin to disperse. Along the South Atlantic coast, they utilize a variety of inshore habitats. Included are tidal freshwater habitats and the low-salinity reaches of estuaries, estuarine emergent vegetated wetlands (flooded salt marshes, brackish marsh and tidal creeks), estuarine scrub/shrub (mangrove fringe), submerged aquatic vegetation (SAV), oyster reefs and shell banks, and unconsolidated bottom (soft sediments) (SAFMC 1998b).

In general, juvenile red drum are found throughout South Atlantic estuaries in all of the habitat types described above. In the Chesapeake Bay, juveniles (20 - 90 mm TL) were collected in shallow waters from September to November, but no indication as to the characteristics of the habitat was given (Mansueti 1960). According to Nelson et al. (1991), South Atlantic estuaries where juveniles (including subadults) are abundant are Bogue Sound, North Carolina; Winyah Bay, South Carolina; Ossabaw Sound, and St. Catherine/Sapelo Sound, Georgia; and the St. Johns River, Florida. They are highly abundant in the Altamaha River and St. Andrew/St. Simon Sound, Georgia, and the Indian River, Florida.

Red drum begin the subadult phase of their life cycle upon leaving the shallow nursery habitat at approximately 200 mm TL (10 months of age). They are considered subadults until they reach sexual maturity at 3-5 years (C. Wenner, pers. comm.). It is at this stage in their life cycle that red drum utilize a variety of habitats within the estuary and when they are most vulnerable to exploitation (Pafford et al. 1990; Wenner 1992). Tagging studies conducted throughout the species' range indicate that most subadult red drum tend to remain in the vicinity of a given area (Beaumarriage 1969; Osburn et al. 1982; Music and Pafford 1984; Wenner, et al. 1990; Pafford et al. 1990; Ross and Stevens 1992; Woodward 1994; Marks and DiDomenico 1996). Movement within the estuary is most likely related to changes in temperature and food availability (Pafford et al. 1990; Woodward 1994).

<u>North Carolina</u>

The state of North Carolina has 147,000 acres of designated Primary Nursery Areas (PNA) and

Secondary Nursery Areas (SNA) that generally comprise the upper reaches of tidal creeks and rivers and may include coastal wetlands, shell-bottom and soft sub-tidal bottom habitats (NCDMF 2001). The North Carolina Division of Marine Fisheries (NCDMF) surveys of juvenile red drum have documented their presence from the Cape Fear River, north through Buzzards Bay in Dare County (Ross and Stevens 1992). Juvenile red drum were consistently abundant in shallow waters (< 5 feet) near the mouths of the Pamlico and Neuse Rivers and in smaller bays and rivers between them.

Tagging studies indicate that late age-0 and 1 year-old red drum are common throughout the shallow portions of the estuaries and are particularly abundant along the shorelines of rivers and bays, in creeks, and over grass flats and shoals of the sounds. During the fall, those subadult fish inhabiting the rivers move to higher salinity areas such as the grass flats and shoals of the barrier islands and the front beaches. Fish that reside near inlets and along the barrier islands during the summer are more likely to enter the surf in the fall. During the winter, most subadults are recaptured in the estuaries, although some are taken in the surf and inlets. During spring and summer, recaptures are common along the barrier islands, near coastal inlets, and in the surf zone, with a large number of the subadults continuing to frequent the rivers. By their second and third year of growth, red drum are less common in rivers. Instead, they are found along the barrier islands, inhabiting the shallow water areas around the outer bars and shoals of the surf and in coastal inlets over inshore grass flats, creeks or bays.

South Carolina

Smallest juveniles were observed in the creeks from August through October, indicating that this is the time when red drum recruit to nursery areas in South Carolina. With the onset of winter temperatures, juveniles left the shallow creeks for deeper water in the main channels of rivers (9 - 15 m) and returned again to the shallows in the spring. Juveniles are also present in areas where low salinities do not occur, i.e. behind the barrier islands on the Isle of Palms, Capers Island, Bulls Island (C. Wenner, pers. comm.). Thus, the shallow areas of tidal creeks that run through *Spartina alterniflora* dominated marshes throughout the coast are the primary nursery areas for red drum in South Carolina. Subadult red drum have been observed in larger tidal creeks and rivers, near inlets, jetties, sandbars, and even nearshore artificial reefs (Wenner 1992). Some of the subadult red drum in South Carolina also temporarily inhabit the front beaches of barrier islands. During winter months, schools of subadult red drum have been sighted in sheltered, shallow inshore areas. During 1994 and 1995, the Inshore Fisheries Section of the South Carolina DNR conducted several aerial surveys to attempt to evaluate abundance and habitat utilization of subadult red drum along the South Carolina coast. Aerial surveys were generally deemed inefficient at estimating the number of fish inhabiting particular areas, especially inlets and beachfront areas because the visibility of schools from the air depends on the interplay of temporal, climactic, topographic and behavioral factors. On the occasions when red drum schools were reliably located, they were found in flats at the confluence of rivers, inside inlets, creeks, sounds and bays. Aerial surveys proved useful to characterize the general topography of subadult red drum habitat in the intertidal and shallow-subtidal portions of the coast. It appears that typical habitats where subadult red drum are found in South Carolina are of two general types. In the northern portion of the coast, typical subadult habitat consists of broad (up to 200 m or more in width), gently sloping flats often leading to the main channel of a river or sound. Along the southern portion of the coast, subadult red drum habitat consists of more narrow (50 m or less), fairly level flats traversed by numerous small channels, typically 5-10 m wide by less than 2 m deep at low tide).

Salinity

In South Carolina estuaries, juvenile red drum have been collected over a range of salinities in shallow tidal creeks and in tidal impoundments. Daniel (1988) collected post-larval and juvenile red drum (6 – 13 mm SL) in the upper reaches of the Wando River estuary and off the Intracoastal Waterway from August through December. Collection sites were characterized by shell hash, sand and mud bottom. Juveniles were rare in the tidal creeks throughout the winter and they reappeared in the collections again in the spring. Similarly, Wenner et al. (1990) collected post-larval and juvenile red drum from June 1986 through July 1988 in shallow tidal creeks in temperatures from 9 to 30° C and salinities from 0.8 to 33.7 ppt.

In Georgia, Dahlberg (1972) collected juvenile red drum along beaches, in tidal canals, and low- and high-salinity tidal pools of the Sapelo Sound and St. Catherine's Sound estuarine systems in Georgia.

In a study conducted by Bacheler *et al.* (2009a), age-0 to age-3 red drum are commonly found in upper estuarine environments, but each fall a portion of age-1 and age-2 cohorts move to high-salinity coastal waters, while some red drum remain in upper estuarine habitat until age-3; at this age the last remaining red drum move to coastal environments.

Substrate

In general, habitats supporting juvenile red drum in North Carolina can be characterized as detritus or mud-bottom tidal creeks in western Pamlico Sound, and mud or sand bottom habitat in other areas (Ross and Stevens 1992). Within SAV beds, investigations have shown juveniles to prefer areas with patchy grass coverage over sites with homogeneous vegetation (Mercer 1984, Ross and Stevens 1992, Rooker and Holt 1997).

Juvenile red drum utilize a variety of inshore habitats within the estuary, including seagrass meadows, tidal freshwater, low-salinity reaches of estuaries, estuarine emergent wetlands, estuarine scrub/shrub, submerged aquatic vegetation, oyster reefs, shell banks, and unconsolidated bottom (SAFMC 1998; ASMFC 2002). Smaller red drum seek out and inhabit rivers, bays, canals, boat basins, and passes within estuaries (Peters and McMichael 1987; FWCC 2008). Wenner’s studies (1992) indicate that red drum juvenile habitats vary slightly seasonally: most often between August and early October, red drum inhabit small creeks that cut into emergent marsh systems and have some water in them at lower tides, while in winter, red drum reside in main channels of rivers ranging in depths from 10 to 50 feet with salinities from one-half to two-thirds that of seawater.

The subadult phase of the red drum’s life cycle begins when late-stage juveniles leave shallow nursery habitats at a size of approximately 200 mm TL and 10 months of age. These subadults later attain sexual maturity, at about 3-5 years of age. Subadult red drum are most vulnerable to fishery exploitation (Pafford *et al.* 1990; Wenner 1992). They utilize many habitats within the estuary, including tidal creeks, rivers, inlets, and waters around barrier islands, jetties and sandbars (Pafford *et al*. 1990; Wenner 1992). While subadults are found in habitats similar to that of juvenile red drum, they are also found in large aggregations on seagrass beds, over oyster bars, mud flats, and sand bottoms (FWCC 2008).

In the Chesapeake Bay, juveniles (20-90 mm Total Length, TL) were collected in shallow waters from September to November, but there is no indication as to the characteristics of the habitat (Mansueti 1960). Some southeastern estuaries where juvenile (and subadult) red drum are abundant are Bogue Sound, NC; Winyah Bay, SC; Ossabaw Sound, and St. Catherine/Sapelo Sound, GA; and the St. Johns River, FL (Nelson *et al.* 1991) and throughout SC (Wenner *et al.* 1990; Wenner 1992). They were highly abundant in the Altamaha River and St. Andrews/St. Simon Sound, GA, and the Indian River, FL (Nelson *et al*. 1991).

Peters and McMichael (1987) found in Tampa Bay that juvenile red drum were most abundant in protected backwater areas, such as rivers, tidal creeks, canals, and spillways with freshwater discharge, as well as in areas with sand or mud bottom and vegetated or non-vegetated cover. Juveniles found at stations with seagrass cover were generally smaller in size and fewer in number (Peters and McMichael 1987). Near the mouth of the Neuse River, as well as smaller bays and rivers between Pamilico Sound and the Neuse river, surveys from the North Carolina Division of Marine Fisheries (NCDMF) indicate that juvenile red drum were consistently abundant in shallow waters of less than 5 feet. Generally, habitats identified as supporting juvenile red drum in North Carolina can be characterized as detritus laden or mud-bottom tidal creeks (in Pamlico Sound) and mud or sand bottom habitat in other areas (Ross and Stevens, 1992). In a Texas estuary, young red drum (6-27 mm Standard Length, SL) were never present over non-vegetated muddy-sandy bottom; areas most abundant in red drum occurred in the ecotone between seagrass and non-vegetated sand bottom (Rooker and Holt 1997). In SC, Wenner (1992) indicated that very small red drum occupy small tidal creeks with mud/shell hash and live oyster as common substrates (since sub-aquatic vegetation is absent in SC estuaries).

Temperature

In the winter of their first year, 3 to 5 month old juveniles migrate to deeper, more temperature-stable parts of the estuary during colder weather (Pearson 1929). In the spring, they move back into the estuary and shallow water environments. In the following spring, juveniles become more common in the shallow water habitats.

Dissolved Oxygen

Feeding Behavior

Tagging studies conducted throughout the species' range indicate that most subadult red drum generally remain in the vicinity of a given area (Beaumarriage 1969; Osburn *et al.* 1982; Music and Pafford 1984; Wenner *et al.* 1990; Pafford *et al.* 1990; Ross and Stevens 1992; Woodward 1994; Marks and DiDomenico 1996). Movement within estuaries is assumed to be related to temperature changes and food availability (Pafford *et al.* 1990; Woodward 1994).

Spot

Competition and Predation

Part D. Adult Habitat

Along the Atlantic Coast adult red drum migrate north and inshore in the spring. In the fall, they migrate offshore and south. Overall, adults tend to spend more time in coastal waters after reaching sexual maturity. However, they do continue to frequent inshore waters on a seasonal basis. Less is known about the biology of red drum once they reach the adult stage and accordingly, there is a lack of information on habitat utilization by adult fish. The SAFMC's Habitat Plan (SAFMC 1998b) cited high salinity surf zones and artificial reefs as essential fish habitat (EFH) for red drum in oceanic waters, which comprise the area from the beachfront seaward. In addition, nearshore and offshore hard/live bottom areas have been known to attract concentrations of red drum. The following description of these habitats was adapted from that provided in the SAFMC's Habitat Plan (1998b).

Geographic and Temporal Patterns of Migration

Salinity

The SAFMC's Habitat Plan (SAFMC 1998b) cited high salinity surf zones as an essential fish habitat (EFH) for red drum in oceanic waters, which comprise the area from the beachfront seaward.

Substrate

In addition to natural hard/live bottom habitats, adult red drum also use artificial reefs and other natural benthic structures. As of 2002, 120,000 acres of ocean and estuarine bottom along the south Atlantic has been permitted for the development of artificial reefs (ASMFC 2002). In Florida alone, 34 out of 35 coastal counties have been involved in artificial reef development (FWCC 2012). Most Atlantic coast states are in the process of establishing or have already established artificial reef management programs in their coastal waters.

Red drum were found from late November until the following May at both natural and artificial reefs along tide rips or associated with the plume of major rivers in Georgia (Nicholson and Jordan 1994). Data from this study suggests that adult red drum exhibit high seasonal site fidelity to these features. Fish tagged in fall along shoals and beaches were relocated 9 to 22 km offshore during winter and then found back at the original capture site in the spring. In summer, fish moved up the Altamaha River nearly 20 km to what the authors refer to as “pre-spawn staging areas” and then returned to the same shoal or beach again in the fall.

Temperature

Bottom water temperatures in deeper hard/live bottom areas range from approximately 11-27° C whereas inshore areas typically exhibit cooler temperatures. Data are part of SEAMAP's South Atlantic Bottom Mapping Work Group effort, which began in 1992.

Spot

Dissolved Oxygen

Feeding Behavior

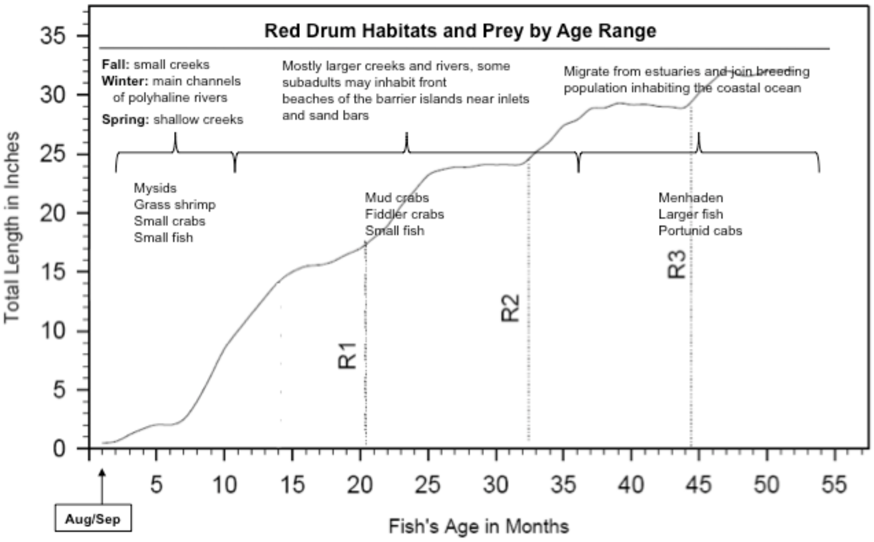

Figure 1. Red drum habitats and primary prey by age and size. Figure adapted from Wenner (2004) and based on research in South Carolina. R1, R2, and R3 are the ages of red drum when they have deposited 1, 2, or 3 rings on their ear bones or scales.

Competition and Predation

<u>Section II. Essential Fish Habitats and Habitat Areas of Particular Concern</u>

Essential Fish Habitat

The South Atlantic Fishery Management Council recognizes several habitats as Essential Fish Habitat (EFH) for red drum. These natural communities include tidal freshwater, estuarine emergent vegetated wetlands (flooded salt marsh, brackish marsh, and tidal creeks), estuarine scrub/shrub (mangrove fringe), submerged rooted vascular plants (seagrass), oyster reefs and shell banks, unconsolidated bottom (soft sediment), ocean high salinity surf zones, and artificial reefs (SAFMC 1998b). The area covered ranges from Virginia through the Florida Keys, to a depth of 50 m offshore.

Identification of Habitat Areas of Particular Concern

For red drum, this includes the following habitats: tidal freshwater, estuarine emergent vegetated wetlands (flooded saltmarshes, brackish marsh, and tidal creeks), estuarine scrub/shrub (mangrove fringe), submerged rooted vascular plants (sea grasses), oyster reefs and shell banks, unconsolidated bottom (soft sediments), ocean high salinity surf zones, and artificial reefs. The South Atlantic Fisheries Management Council (SAFMC) which has a similar designation for their HAPCs has recognized HAPCs for red drum along the U.S. coast including all coastal inlets, all state-designated nursery habitats (i.e. Primary Nursery Areas in North Carolina), sites where spawning aggregations of red drum have been documented and spawning sites yet to be identified, and areas supporting submerged aquatic vegetation (SAV). The SAFMC (1998b) also cited barrier islands off the South Atlantic states as being of particular importance since they maintain the estuarine environment in which young red drum develop. Passes between barrier islands are of concern because the productivity of the estuary depends on the slow mixing of fresh and seawater that occurs in these areas. Finally, inlets, channels, sounds and outer bars are of particular importance to red drum since spawning activity is known to occur in these areas throughout the South Atlantic. Moreover, subadult and adult red drum utilize these areas for feeding and daily movements.

As previously mentioned, evidence suggests that spawning occurs within passes and inlets and inside high salinity estuaries of the southeast U.S. coast. Hence, all such geographic features throughout the red drum's range constitute potential spawning habitat and are of critical importance to the species' survival. Specific areas of the Atlantic coast where red drum spawning is currently known to take place are: North Carolina - waters of Pamlico Sound near Hatteras, Ocracoke and Drum Inlets and between the Neuse and Pamlico rivers in the western portion of the sound; South Carolina - main channel leading to Charleston Harbor and estuarine waters of St. Helena Sound; Georgia - the Altamaha River estuary; Florida – Ponce de Leon inlet and the Mosquito Lagoon system.

A species’ primary nursery areas are indisputably essential to its continuing existence. Primary nursery areas for red drum can be found throughout estuaries, usually in shallow waters of varying salinities that offer certain degree of protection. Such areas include coastal marshes, shallow tidal creeks, bays, tidal flats of varying substrate, tidal impoundments, and seagrass beds. Since red drum larvae and juveniles are ubiquitous in such environments, it is impossible to designate specific areas as deserving more protection than others. Moreover, these areas are not only primary nursery areas for red drum, but they fulfill the same role for numerous other resident and estuarine-dependent species of fish and invertebrates.

Similarly, subadult red drum habitat extends over a broad geographic range and adheres to the criteria that define HAPCs. Subadult red drum are found throughout tidal creeks and channels of southeastern estuaries, in backwater areas behind barrier islands and in the front beaches during certain times of the year. Therefore, the estuarine system as a whole, from the lower salinity reaches of rivers to the mouth of inlets, is vital to the continuing existence of this species.

SAFMC HAPC Designations for Red Drum

Of the designated EFH, Habitat Areas of Concern (HAPC) have been recognized for red drum by the SAFMC. Areas which meet the criteria for HAPC include all coastal inlets, all state-designated nursery habitats of particular importance to red drum, documented sites of spawning aggregations from North Carolina to Florida, other spawning areas identified in the future, and areas supporting submerged aquatic vegetation (SAV) (SAFMC 1998b). These HAPC include the most important habitats required during the life cycle of the species, including spawning areas and nursery grounds. Other areas of concern are barrier islands, since these geological formations are vital to maintain estuarine conditions needed by larval and juvenile stages. Inlets between barrier islands are also very important, as the slow mixing of seawater and freshwater is critical to the ecological functioning of an estuary, including maintenance of salinity and current regimes and the creation of sandy shoals. Unnatural or human-induced changes that reduce or increase flow into estuaries may result in environmental stress in organisms (SAFMC 1998b).

Present Condition of Habitat Areas of Particular Concern

Red drum populations along the Atlantic coast are managed through the Atlantic Coastal Fisheries Cooperative Management Act (Atlantic Coastal Act). Unlike the Magnuson-Stevens Fishery Conservation and Management Act which addresses fishery management by federal agencies, the Atlantic Coastal Act does not require the Atlantic States Marine Fisheries Commission to identify habitats that warrant special protection because of their value to fishery species. Nonetheless, the Commission believes this is a good practice so that appropriate regulatory, planning, and management agencies can consider this information during their deliberations.

As reviewed in section 1.4.1.1, habitats used by the various life stages of red drum include: tidal freshwater wetlands, estuarine wetlands, tidal creeks, mangrove wetlands, submerged aquatic vegetation (SAV), oyster reefs and shell banks, ocean high-salinity surf zone, hard bottom, and natural and artificial reefs. Spawning occurs within passes and inlets of high salinity estuaries on the southeastern U.S. coast and outer bars within surf zones (Murphy and Taylor 1990; Johnson and Funicelli 1991; Nicholson and Jordan 1994; Woodward 1994). In more recent studies, increased spawning habitat of red drum upriver to Oriental, NC, was due to elevated levels in salinity (Beckwith *et al*. 2006). Specific “hot spots” for red drum spawning include: North Carolina – waters of Pamlico Sound near Hatteras, Ocracoke and Drum Inlets and between the Neuse and Pamlico rivers in the western portion of the sound; South Carolina – main channel leading to Charleston Harbor and estuarine waters of St. Helena Sound; Georgia – the Altamaha River estuary; Florida – Ponce de Leon inlet and the Mosquito Lagoon system (ASMFC 2002). For red drum, nursery areas exist throughout estuarine environments, usually in shallow waters with varying salinities. Areas included are coastal marshes, shallow tidal creeks, bays, tidal flats of varying substrate type, tidal impoundments, and SAV beds. Red drum larvae and juveniles occur within a broad range of estuarine habitats. Similarly, subadult red drum are found throughout tidal creeks and channels of southeastern estuaries, in backwater areas behind barrier islands, and in the front along ocean beaches during certain seasons. Estuarine systems as whole, ranging from lower salinity rivers to the mouths of inlets, are needed to support populations of red drum.

A subset of red drum habitats, which the Commission refers to as Habitats of Concern (HOC), is especially important as spawning and nursery areas for red drum. HOC for red drum include all coastal inlets, SAV beds, the surf zone (including outer bars), and state-designated nursery habitats (e.g., Primary Nursery Areas in North Carolina; Outstanding Resource Waters in South Carolina's coastal counties; Aquatic Preserves along the Atlantic coast of Florida).

Coastal Spawning Habitat: Condition and Threats

The productivity and diversity of coastal spawning habitat can be compromised by the effects of industrial, residential, and recreational coastal development (Vernberg *et al.* 1999). Coastal development continues in all states and coastlines of the nation despite the increased protection afforded by federal and state environmental regulations. Threats to nearshore habitats in the south Atlantic that are documented spawning habitats for red drum or are suitable spawning habitats are described below.

Navigation and boating access development and maintenance activities, such as dredging and hazards from ports and marinas, are a threat to spawning habitats of red drum. According to the SAFMC (1998) and ASMFC (2002), navigation related activities can result in removal or burial of organisms from dredging or disposal of dredged material, effects due to turbidity and siltation, release of contaminants and uptake in nutrients, metals and organics, release of oxygen-consuming substances, noise disturbance, and alteration of hydrodynamic regime and habitat characteristics. All listed effects have potential effects to decrease the quality and quantity of red drum spawning habitat.

Ports also pose the threat of potential spills of hazardous materials. Cargo that arrives and departs from ports can contain highly toxic chemicals and petroleum products. While spills are rare, constant concern exists for extensive spans of estuarine and nearshore habitat being at risk of contamination. Even a small spill could result in a huge exposure of productive habitats. Oil releases such as the MC 282 or Deepwater Horizon oil release (2010) into the Gulf of Mexico has severely affected aquatic life, water quality and habitat posing many threats such as mortality, disease, genetic damage, and immunity issues (Collier *et al.* 2010). Chemicals in crude oil can cause heart failure in developing fish embryos (Incardona *et al.* 2004, 2005, 2009). Chronic exposures for years after the Exxon Valdez oil spill were evident in fish and other marine life, resulting in a higher pattern of mortality (Ballachey *et al.* 2003). Oiling of nearshore high-energy habitat along beaches of the Gulf of Mexico from Louisiana to Florida occurred for prolonged periods of time during the spring of 2010, and weathered oil products were found in offshore benthos where spawning red drum can occur. The discharge of oil may have also altered migration patterns and food availability. Port discharge of marine debris, garbage, and organic waste into coastal waters is also a concern.

Beach nourishment projects and development of wind and tidal energy could also alter red drum spawning and offshore adult habitat dynamics. Beach nourishment can result in removal of offshore sediments resulting in depressions and altering sediment characteristics along the shoreline (Wanless 2009). Sediments eroded from beaches after nourishment projects can also be transported offshore and bury hard bottoms, which can diminish spawning aggregation habitat for red drum. Beach nourishment projects can also alter forage species abundance, distribution and species composition in the high-energy surf zone for a time, but this varies by species and timing of nourishment activities (Irlandi and Arnold 2008). Wind and tidal energy projects can create artificial structure in migration corridors and submarine cables may produce electrical fields that can affect red fish movement patterns and habitat use in affected areas (DONG 2006; OEER 2008; ASMFC-Habitat Committee 2012).

Use of certain types of fishing gear, such as trawls and bivalve dredges can also adversely affect spawning habitat (Northeast Region Essential Fish Habitat Steering Committee 2002). Trawls and dredges remove structure-forming epifauna, alter sediment contours, redistribute reef aggregate materials (e.g. fractured rock outcroppings and boulders) and change infaunal and demersal organism assemblages in areas where fishing gear is operated. These effects can reduce forage species abundance for red drum thereby affecting spawning success. The most significant effect of this type of fishing gear is long-term changes in bottom structure and long-term changes in benthic trophic or ecosystem functions. These effects can be on the order of months to years in low energy environments, so alterations can have a long-term effect on red drum spawning habitat.

Spawning is optimal within a specific range of temperatures. Climate change and resulting temperature regime changes in spawning habitats could alter the timing of spawning and egg development, which may be detrimental in a specific habitat area of concern. Such alterations in phenology are recognized as such a threat to the survival of many species (USFWS 2011). Significant climate change could alter current patterns and significantly change water temperatures, affecting migration and spawning patterns, and larval survival (Hare and Able 2007; USFWS 2011).

Estuarine Spawning, Nursery, Juvenile and Subadult Habitat: Condition and Threats

Between 1986 and 1997, estuarine and marine wetlands nationwide experienced an estimated net loss of 10,400 acres (Dahl 2000). The majority of this loss was from urban and rural activities and the conversion of wetlands for other uses. Along the south Atlantic coast, Florida experienced the greatest loss due to urban or rural development (Dahl 2000). In Tampa Bay, 3,250 acres of seagrass have been recovered between 2008 and 2010 (EPA 2011b).

Conditions of red drum estuarine habitats vary depending on the level of urbanization. Generally, an estuarine environment closer to a highly developed urban area will exhibit degradation when compared to the quality of estuarine habitat with less development of its surrounding landscape. Runoff, waste, and sewage pollution of sensitive coastal environments and can result in the proliferation of pathogens. Pathogens can result in lesions, developmental issues, disease of major organs, and mortality in red drum and other fishes (Conway *et al.* 1991) Red drum may exhibit a higher tolerance to bacteria with age, and antibody response also increases as water temperature does (Evans *et al.* 1997). Atrazine, a widely used pesticide in the United States, was exposed to red drum in low levels to test its' affect on growth, behavior, and survival of red drum. In laboratory experiments, using realistic doses of atrazine with respect to runoff amounts, red drum larvae exhibited a 7.9% - 9.8% decrease in growth rate (Alvarez & Fuiman 2005).

Nutrient enrichment of estuarine waters is a major threat to water quality and habitat available to the red drum. In the southeast, forestry practices significantly contribute to nutrient enrichment, as does pesticide use, fertilizers, and pollution runoff (ASMFC 2002; NSCEP 1993). Urban and suburban development are the most immediate threat to red drum habitat in the southeast. Port and marina expansion also impact the estuarine habitat important to red drum by pollution contributed from stormwater originating from altered uplands and through alterations to hydrodynamic flows and tidal currents. Watercraft operation can result in pollutant discharge, contributing to poor water quality conditions. Facilities supporting watercraft operations also result in the alteration and destruction of wetlands, shellfish and other bottom communities through construction activities. Motorized vehicles in Class A (< 16 ft) and Class 1 (16 to 25 feet) have seen major recreational growth in estuarine waterways (NMMA 2004). Operation of watercraft equipped with outboard and inboard engines and propellers over shallow seagrass communities can cause increased seagrass scarring (Sargent *et al.* 1995). Mining activities in nearby areas can also pose a threat with nutrient and contaminant runoff, dredging material deposition, and through alternations of the hydrology of the estuary.

Hydrologic modifications can negatively affect estuarine habitats. Aquaculture, mosquito control, wildlife management, flood control, agriculture, and silviculture activities can result in altered hydrology. Ditching, diking, draining, and impounding activities also qualify as hydrologic modifications that can impact estuarine environments (ASMFC 2011). Alteration of freshwater flows into estuarine areas may change temperature, salinity, and nutrient regimes as well as wetland coverage. Studies have shown that alteration in salinity and temperature can have profound effects in estuarine fishes (Serafy *et al.* 1997) and that salinity can dictate the abundance and distribution of organisms residing in estuaries (Holland *et al.* 1996). Certain areas in the southeast concern the maintenance and stabilization of coastal inlets. Construction of groins and jetties has altered hydrodynamic regimes and in turn, transport of larvae of estuarine dependent organisms through inlets (Miller *et al.* 1984; Miller 1988).

Shoreline erosion patterns can also affect the hydrodynamics and transport of larvae to estuarine environments. Erosion has the potential to alter the freshwater flow into habitats essential for egg, larval, and juvenile survival. Whether erosion is human-induced or naturally occurring, nearshore habitats are consequently affected and eroded sediment is transported and deposited elsewhere (ASFMC 2010). Beach nourishment activities can result in sedimentation in estuaries, covering seagrass beds and other nearshore habitats, and causing water quality to deteriorate (Green 2002; DEP 2011). Along the Atlantic coast, living shorelines are becoming a more popular management strategy to control and minimize erosion (ASFMC 2010).

As with other red drum habitat, trawl fisheries represent a threat to estuarine habitat for this species. In combination with the physical and biological effects identified in the Northeast

Region Essential Fish Habitat Steering Committee workshop proceedings (2002), trawling activities and bivalve harvesting activities(oyster tonging, clam raking, clam kicking, etc.) can severely damage seagrass systems (Stephan *et al*. 2000). Such activities can reduce the productivity of estuarine red drum habitat and alter the ecology of this habitat. Forage species abundance can diminish and movement patterns for red drum schools within the estuaries they inhabit can be altered. Effects of these fishing gears can be ameliorated through effective management strategies, such as exclusion of trawl fisheries from seagrass communities, but without such management, the adverse effects of the fishery activities can be long-term.

Climate change has the potential to cause sea level rise, which could result in faster erosion of certain nearshore areas and loss of shallow nursery habitats to inundation. Projections of global sea level rise are from 18-59 cm by the year 2100, with an additional contribution from ice sheets of up to 20 cm (IPCC 2007). In addition to sea level rise, climate change could alter the amount of freshwater delivery and salinity levels in estuarine areas (USFWS 2011). Estuarine environments are highly vulnerable to changes in climate, so any change in temperature regime is also a concern. As temperature increases, the surface water in estuaries and marshes increases, which makes oxygen solubility more difficult (EPA 2011a) and can stress the environment. This can also minimize saltwater and freshwater mixture, and affect nutrient supply by changing hydrodynamics. Increases in carbon dioxide levels in ocean water, as a result of climate change, causes rises in acidity and pH levels. Estuarine waters are vulnerable to acidification, but seagrasses are particularly susceptible to changes in water column acidity (EPA 2011a).

Increases in temperature can also affect metabolism of seagrass (Evans *et al.* 1986, Marsh *et al.* 1986; Bulthuis 1987; Zimmerman *et al*. 1989b; Neckles and Short 1999), which alter the carbon balance and nutrient cycle. Changes could result in alterations in species distribution and abundance varying both geographically and spatially (McMillan 1984; Walker 1991).

Adult Habitat: Condition and Threats

While threats to adult red drum habitat exist, they are not as numerous as those faced by post-larvae, juveniles, and subadults in estuarine and coastal waters. According to the SAFMC (1998) and ASMFC (2002), threats to both nearshore and offshore habitats that adult red drum utilize in the south Atlantic include navigation management and related activities; dredging and dumping of dredged material; mining for sand or minerals; oil and gas drilling and transport; and commercial and industrial activities, and are similar to those for red drum coastal spawning habitat as mentioned in section 1.4.3.1 above.

Currently, mineral mining activities in the South Atlantic are highly limited. Offshore mining has the potential to pose a threat to adult red drum habitat in the future. Mining activities could alter the hydrology, sediment landscape, and water quality of surrounding areas, affecting both fish and their habitat, by causing sediment plumes or releasing metallic substances into the water column (Halfar 2002).

A more immediate threat to red drum adult habitat is the mining of sand for beach nourishment projects. Associated risks include burial of hard bottoms near mining or disposal sites, contamination, and an increase in turbidity and hydrological alterations that could result in a diminished habitat (Green 2002; Peterson and Bishop 2005).

Although adult red drum are euryhaline and eurythermal, drastic or sudden changes in salinity or temperature can result in mortality (Gunter 1941; Buckley 1984). While climate change is not an immediate threat, drastic fluctuations in seasonal temperature regimes and predicted extreme weather events could potentially pose threats the future.

Section II. Threats and Uncertainties

Significant Environmental, Temporal, and Spatial Factors Affecting Distribution of [Species]

Red drum utilize all available estuarine and nearshore habitats throughout their life history. Although regional habitat types, such as mesohaline SAV communities, might be limited locally, red drum can use multiple habitat types at each stage of their development. There is no supporting evidence that habitat is currently limiting to populations of red drum throughout their range.

For example, oyster reefs are an important habitat to red drum at the juvenile and subadult life stages. In South Carolina, the abundance of red drum is not limited by the availability or health of oyster reef habitat, despite significant reductions of oyster reef habitat throughout the range of the red drum population. Data from Georgia's Marine Sportfish Health Survey (MSPHS) suggests over 80% of all juvenile red drum (< 375mm CL) captured since 2003 are associated with shell/oyster habitat. In comparison, less than half of the stations sampled were associated with shell. Since red drum use multiple habitat types at each stage of their development, limitation of one habitat type does not necessarily reduce survival of that life stage's cohort.

Creeks, tributaries, and estuaries are important habitats for red drum. Larval, juvenile, and subadult red drum are particularly sensitive to pollution contributed by watershed scale human activities. There is currently no evidence that chemical pollution is a limiting factor for juvenile and subadult red drum. However, changes in hydrology due to watershed activities that alter stormwater flow and sedimentation might restrict red drum larval recruitment both locally and regionally. The potential for impact on larval red drum recruitment is dependent upon the scale of stormwater change within the watershed and creek systems. Additionally, sediment accumulation may alter SAV abundance and circulation patterns resulting in lower recruitment into small creeks.

Spot

While these sensitive habitats have been identified as important to various life stages of red drum, none of them are believed to currently limit the successful recruitment of red drum individuals to regional stocks.

Unknowns and Uncertainties

Section IV. Recommendations for Habitat Management and Research

Habitat Management Recommendations

[Management recommendations can be developed from “Ecosystem Considerations” section, as a start.]

Habitat Research Recommendations

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CHAPTER 5: Spot

Populated with text from the Omnibus Amendment to the ISFMP for Spanish Mackerel, Spot, and Spotted Seatrout (2012)

Section I. General Description of Habitat

Spot are found in estuaries and coastal areas from the Gulf of Maine to the Bay of Campeche, Mexico, and are concentrated between the Chesapeake Bay to South Carolina (Phillips et al. 1989). Juvenile spot prefer shallow water areas, less than 8m, over fine sediment and in tidal marshes (Phillips et al. 1989; Strickney and Cuenco 1982; Chesapeake Bay Program 1991). Juvenile spot are found in salinities ranging from 0 to 30 ppt and water temperatures from 5º to 30ºC (Stickney and Cuenco 1982; Phillips et al. 1989, ASMFC 1987), and therefore are found from polyhaline to freshwater nursery areas. Adult spot are more abundant in coastal waters and lower estuaries and less abundant in lower salinity areas, compared to juveniles.

Part A. Spawning Habitat

Data indicate that spot spawn further offshore and in deeper waters than other sciaenids. Spot typically migrate offshore and spawn in the relatively deep water of the outer continental shelf, though some evidently spawn in both nearshore waters and estuaries (Dawson 1958; Lewis and Judy 1983). Ripe adults aggregate off beaches in fall and begin migration offshore, possibly migrating to more southern waters in the process (Pearson 1932). Spot may spawn repeatedly over several weeks (Hildebrand and Cable 1930), with some individuals remaining offshore after spawning (Pearson 1932; Wenner et al. 1979, 1980). Fall migrations of maturing spot to offshore waters were reported from Chesapeake Bay (Hildebrand and Schroeder 1928), North Carolina (Roelofs 1951), and South Carolina estuaries (Dawson 1958). Ripe spot were collected in depths up to 82 m off South Carolina (Dawson 1958) and 8−10 mi off the Georgia coast (Hoese 1973). Smith (1907) stated that in North Carolina spot spawn in the sounds and inlets and Hildebrand and Cable (1930) suggested that spawning occurred in close proximity to passes off North Carolina; however, no evidence was offered to support these statements. Larval distributions of spot also indicate that spawning occurs more heavily offshore (26−128 m) than inshore (14.6−20.1 m; Berrien et al. 1978; Lewis and Judy 1983; Warlen and Chester 1985).

Geographic and Temporal Patterns of Migration

Many adult spot have moved out of estuaries by the fall or have spent a year (after year-1) in nearshore habitats. Following the fall migration to nearshore habitats, some adults may spawn on the inner continental shelf during the late fall, if water temperatures remain warm enough. Otherwise, it is assumed that adults migrate to the outer continental shelf where temperatures are suitable for spawning and egg development (17.5 to 25ºC; Hettler and Powell 1981). Compared to other sciaenids, spawning spot are further offshore and in deeper waters. Ripe spot have been collected in depths up to 82 m off South Carolina (Dawson 1958) and shallower waters 8−10 mi off the Georgia coast (Hoese 1973). It is unknown what proportion of spent adults return inshore, or any other habits or behaviors they exhibit (other than the assumption that some proportion return to nearshore or estuarine waters).

Salinity

There is no evidence that spawning individuals experience anything less than full seawater based on their offshore location and habitat needs.

Substrate

While the behaviors of juvenile and adult spot likely center on feeding, and thus substrate, it is unknown to what degree substrate influences spawning individuals. Based on the time of year and the offshore habitats required for spawning, it is unlikely that substrate plays a prominent role in spot behavior. Additionally, spot eggs are pelagic and positively buoyant, so the need to identify particular substrates for eggs and larvae should not play a role.

Temperature

Temperature may be the strongest driver of spawning spot behavior. Maturing individuals move offshore in the fall, and if capable (probably based on size) spawn in the late fall if water temperatures are still >17.5ºC (Hettler and Powell 1981). If these two conditions are not met, which is likely true for most of the population, mature spot continue their migration offshore to outer continental shelf habitats where higher winter temperatures can be found.

Dissolved Oxygen

Spawning adults likely experience normoxic conditions (>4.0 mg/L DO) offshore, and thus DO is not a limiting factor or strong influence on behavior.

Feeding Behavior

Spawning adult feeding behaviors are likely a continuation of adult feeding, which takes place in the substrate feeding on epifauna and benthic infauna (Chao and Musick 1977); however, it is unknown how much time or effort spawning individuals spend on feeding.

Competition and Predation

It is unknown what competitive factors play a role in spawners, and because food and space are unlikely to limit, environmental constraints (e.g., temperature) are probably greater. Offshore predation of spot is not well documented, but thought to be a continuation of the predation seen in lower estuary and nearshore habitats (e.g., sharks, sciaenids, flounders).

Part B. Egg Habitat

Geographic and Temporal Patterns of Migration

Offshore of the US Southeast Atlantic coast, spot eggs are spawned during the winter months, but spawning often extends from late fall to early spring (Flores-Coto and Warlen 1993). Exact locations of spawning are not documented, though based on spawning temperature requirements of 17.5 to 25°C (Hettler and Powell 1981), eggs may be spawned in the inner continental shelf early in the spawning season before temperatures decrease. It is likely, however, that the majority of spot eggs are spawned after the fall on the outer continental shelf as this is the only offshore location supporting temperatures high enough for spawning (Warlen and Chester 1985). Detailed descriptions of the egg (and larval) inshore advection processes remain an active field of study, although the positively buoyant eggs are likely moved toward the coast from a combination of wind and warm water eddies, such as those from the Gulf Stream. For example, Govoni et al. (2013) found that spot larvae in warm water cyclonic eddies that both advance development (with warm water temperatures) and offer later larval forage (from increased primary productivity).

Salinity

Because the egg stage of spot occurs entirely offshore, full seawater (approximately 35 parts per thousand (ppt) is likely necessary for proper development and transport of eggs, though no studies have explicitly reported any tolerances or thresholds.

Substrate

Because the egg stage of spot occurs entirely offshore and the eggs are positively buoyant in order to use sea surface transport to move them toward coastal areas, substrate is not considered a critical aspect of spot egg habitat.

Temperature

With relatively high spawning temperature requirements of 17.5 to 25°C (Hettler and Powell 1981) and the observation of larvae (≤ 15 days old) in similarly warm environments (Warlen and Chester 1985), spot egg temperature requirements are likely also high. Under laboratory conditions at 20°C, which is likely a realistic temperature based on empirical data, spot eggs hatched within 48 hours (Powell and Gordy 1980).

Dissolved Oxygen

Because the egg stage of spot occurs entirely offshore, eggs are likely only ever exposed to normoxic waters (5–8 mg/L). It is not currently thought that dissolved oxygen is a limiting factor to survival of spot eggs.

Feeding Behavior

Spot eggs subsist entirely off the yolk sac prior to hatch.

Competition and Predation

Spot eggs likely do not enter into any meaningful ecological competition, as their habitat demands are basic (temperature, salinity, and oxygen requirements largely met by the offshore conditions). Predation of eggs undoubtedly occurs but has not been well studied or reported. Although potentially large numbers of eggs are killed from predation, there is no reason to think that pelagic oceanic predators are targeting spot eggs over other, similar pelagic eggs.

Part C. Larval Habitat

Geographic and Migration Patterns

Larval spot begin after hatching from an egg, usually just days after spawning. Powell and Gordy (1980) report that the yolk sac and oil globule were absorbed within 5 days of hatch, in a laboratory setting and at 20°C. Newly hatched larvae are likely still close to offshore spawning locations, which have been suggested to be up to or beyond 90 km offshore (Flores-Coto and Warlen 1993). Larvae cover (through a combination of passive and active migration or transport) perhaps the largest geographic distance of any life stage of spot, with the possible exception of adults migrating for spawning. As with the egg stage, larvae depend on wind and currents (e.g., warm water eddies) for transportation and do much of their developing in the continental shelf waters during the winter (Able and Fahay 2010). In the winter and through early spring, larval spot ingress into estuarine habitats, often into upper regions of an estuary.

Salinity

Corresponding with the range of habitats seen by larvae, a range of salinities is also experienced. Beginning offshore, full seawater (approximately 35 ppt) dominates until entering coastal estuaries, where salinities likely vary considerably. It is unknown what proportion of larvae settles in upper estuary or oligohaline habitats, but some do and this highlights the full range of salinities that this life stage is capable of experiencing.

Substrate

For the majority of the larval phase, spot are pelagic and not in contact with or preferring a particular type of substrate. During settlement they will interact much more with the substrate, though it remains unclear what (if any) substrate preferences exist for post-settlement larvae.

Temperature

Govoni et al. (2013) reported the densest larval spot concentrations in the continental shelf station, which ranged in temperature from 11 to 19°C. Temperatures for larvae may not be as high as for spawning and egg development as larvae must be transported through waters that are cooler than the offshore waters in which they were spawned. Additionally, spring estuarine water temperatures—particularly in the southeast US—may vary substantially based on atmospheric and terrestrial factors, and thus spot toward the end of their larval phase likely exhibit a wide range of temperatures. Perhaps the greatest temperature threat to larval spot comes from cold temperatures in estuaries. Hoss et al. (1988) reported a stress response to cold temperatures that resulted in an energy deficit at temperatures ≤ 10°C.

Dissolved oxygen

Dissolved oxygen demands are likely met offshore, as well as inshore after ingress. Both of these habitats typically do not experience hypoxic conditions in the winter and early spring, although no published studies have reported on any limitations.

Feeding Behavior

Larval spot are planktonic feeders. Copepods and ostracods are the primary food up to 25 mm standard length (SL; Hildebrand and Cable 1930).

Competition and Predation

Spot larvae likely do not enter into any limiting ecological competition, as their habitat demands are basic—it us unknown whether larvae are limited spatially after settlement, and they are largely planktonic feeders. Predation of larvae undoubtedly occurs both offshore and inshore, yet these processes are difficult to quantify in a way meaningful to the overall population or abundance (i.e., at broad scales and not characterized by spatial or temporal effects of a single study).

Part D. Juvenile Habitat

Tidal salt marshes and larger estuaries are recognized primary nurseries for spot (Weinstein 1979; Currin et al. 1984), although juvenile spot have been frequently collected offshore on the inner continental shelf (Woodland et al. 2012). Due to the generally high productivity of estuaries, this habitat provides ample prey for spot, which feed mostly on small bottom dwelling worms and crustaceans (Chao and Musick 1977). Atlantic coast estuaries are often shallow and structurally complex, providing a physical refuge from predators. In addition, spot are well adapted to live in the physiologically stressful low dissolved oxygen environment of small tidal creeks (Cochran 1994). Research in Rose Bay, North Carolina suggests that during their first summer, spot grow and disperse from shallow edges of the bay to all depths (Currin 1984). Although exceptions exist, this pattern is the generally observed for many coastal species. Geographic and Temporal Patterns of Migration

Salinity

Juvenile spot are found in salinities ranging from 0 to 30 ppt (Phillips et al. 1989; ASMFC 1987), and therefore are found from polyhaline to fresh water in nursery areas. Ross (2003) not only noted the wide distribution of spot with respect to salinity, but also concluded that some of the best primary nursery habitats for spot were in the farthest upstream reaches (in the Cape Fear Estuary, though as with all studies the results should be generalized with caution).

Substrate

Juvenile spot likely have a preference for a substrate type, such as mud (Bozeman and Dean 1980; Strickney and Cuenco 1982). However, a number of studies highlight the opportunistic aspect of spot with regard to habitat. Strickney and Cuenco (1982) report mud being the most suitable, but fine sand and coarse sand still had suitability indices >0.6, suggesting its use. Hettler (1989) concluded that up to 1/3 of juveniles might spend their time in spartina (*Spartina alterniflora*) vegetation and Weinstein and Brooks (1983) reported on the use of seagrass meadows. In many systems across the Atlantic distribution of spot abundance may vary among substrate type, however, spot remain ubiquitous and a distribution-wide substrate preference has not been reported.

Temperature

The preferred temperature range of juvenile spot is 6–20°C, with a tolerable temperature range extending from 1.2–35.5°C (Parker 1971). Juvenile spot are susceptible to winter kill when estuarine temperatures drop suddenly; however, there is likely individual variation in the susceptibility to this source of mortality, and those later-spawned spot (which are smaller in size) likely have lower survival to low temperatures.

Dissolved Oxygen

Much work has been done with regard to spot dissolved oxygen tolerances. This work has been done largely in response to the growing number and size of hypoxic events in coastal rivers and estuaries (Breitburg et al. 2009), and the overlap between where these events occur and where spot inhabit. Originally, Ogren and Brusher (1977) reported DO preferences > 5.0 mg/L, but with tolerances down to 1.3 mg/L. Burton et al. (1980) exposed 90 mm TL juveniles to 0.8 mg/L DO for 96 hours and they largely lived (95% survival), though survival dropped to 5% when DO was lowered to 0.6 mg/L. This suggests a strong (lethal) effect of DO below 0.8 mg/L. Though recent work has begun to show that spot actively avoid hypoxic areas and even inhabit the margins of these areas (Campbell and Rice 2014).

Feeding Behavior

Juvenile spot feed mostly on small bottom dwelling worms and crustaceans (Chao and Musick 1977). Hales and Van Den Avyle (1989) noted the flexibility in juvenile diets, including insect larvae, polychaetes, harpacticoid copepods and other crustaceans. Several studies have reported that spot behavior is often driven more by feeding opportunities than by predation risk (Weinstein and Walters 1982; Miltner et al. 1995; Nemerson and Able 2004), which collectively suggests that prey availability and abundance many drive habitat associations to a greater degree than predators.

Competition and Predation

Density-dependence is often cited as the greatest competitive effect on juvenile spot (Craig et al. 2007), particularly as hypoxia limits available habitat and increases fish densities in suitable areas (Campbell and Rice 2014). Predators of spot include common estuarine predatory fish, such as sharks, seatrout (*Cynoscion spp.*), and flounders (*Paralichthys spp.*), among others (Rozas and Hackney 1984).

Part E. Adult Habitat

Adult spot are common in coastal waters during the spawning season and in estuaries and nearshore waters during the other parts of the year. They are typically found over sandy or muddy bottoms in waters up to approximately 60 m deep.

Geographic and Temporal Patterns of Migration

Designation of ‘adult’ is typically defined by the presence of mature reproductive tissue or after the production of viable gametes (Helfman et al. 2006). Under this designation, it is unknown exactly when spot become adults other than vaguely suggesting around ages-1 or 2 (Hales and Van Den Avyle 1989). Given this transition and the relatively short lifespan of most spot, here we refer to adult spot as those that have lived one year and moved to offshore habitats, which typically takes place around October or November, though in the Chesapeake Bay and estuaries to the south some young-of-the-year may overwinter in estuaries (Able and Fahay 2010). Adults distribute in the inner continental shelf in the fall, while individuals that are mature begin to move farther offshore to warmer waters.

Salinity

Adult spot are tolerant of salinities up to 60 ppt (ASMFC 1987; Phillips et al. 1989) and are more abundant in coastal waters and lower estuaries and less abundant in lower salinity areas, compared to juveniles.

Substrate

Adult spot are bottom-oriented, and require substrates to forage on epifauna and benthic infauna (Chao and Musick 1977). Adults likely prefer muddy substrates to sand or vegetated substrate, which has been reported for juveniles (see juvenile substrate section), although offshore adults will likely utilize sand substrates, which are more common outside of estuaries.

Temperature

As with other habitat variables, adult spot are likely tolerant to a wide range of temperatures, though specifics have not been reported. Despite any tolerances, however, lower temperatures drive migrations offshore in the fall (Pacheco 1962).

Dissolved Oxygen

As with juveniles, adults are likely tolerant of a wide range of DO, but prefer normoxic conditions (> 4.0 mg/L; Chao and Musick 1977). Hypoxic conditions (< 2.0mg/L) are less common offshore, and thus DO is probably less of a concern for adults than for juveniles.

Feeding Behavior

Adult feeding behaviors are a continuation of juvenile feeding, which takes place in the substrate foraging on epifauna and benthic infauna (Chao and Musick 1977). It is unknown whether adult feeding behaviors change offshore.

Competition and Predation

Density dependence may be less of a factor for adults than was for juvenile spot as there are fewer adults than juveniles as well as the fact that lower estuary and offshore habitats are likely to be less spatially limiting than smaller and highly-variable upper estuary environments. Holland et al. (1977) did report sharp mid-summer declines of benthic macroinvertebrates in the Chesapeake Bay, although this occurred largely in upper bay habitats where adults are less likely to inhabit. Predation of spot is dominated by sharks and other estuarine and nearshore predatory fish, such as other sciaenids and flounders (Bowman et al. 2000).

Section II. Essential Fish Habitats and Habitat Areas of Particular Concern

Essential Fish Habitat

Identification of Habitat Areas of Particular Concern

Spot are strongly associated with the bottom as juveniles and adults and are seasonally dependent on estuaries. From Delaware south to Florida, primary nursery habitat includes low salinity bays and tidal marsh creeks with mud and detrital bottoms. Juvenile spot are also found in eelgrass beds in the Chesapeake Bay and North Carolina, however, by late spring juveniles are often much more abundant in tidal creeks than in seagrass habitats. Estuaries, which are especially susceptible to alterations from human activities, are designated as Habitat Areas of Particular Concern (HAPCs) for spot.

- Juvenile spot are particularly associated with the estuary or creek substrates (bottoms, which are often susceptible to degradation from human activities. Additionally, the loss of habitat due to hypoxia is a serious concern across the eastern US (as well as globally), and numerous studies have reported the negative impacts on spot resulting from hypoxic events (Craig et al. 2007; Campbell and Rice 2014).

Present Condition of Habitat Areas of Particular Concern

A number of activities may affect the condition of the habitats utilized by spot. Estuaries are extremely sensitive to dredging, point and nonpoint source pollution and destructive or unregulated practices in siliviculture, agriculture, or coastal development that contribute to increased turbidity. These activities may reduce the quantity and quality of spot habitat.

Section II. Threats and Uncertainties

Significant Environmental, Temporal, and Spatial Factors Affecting Distribution of [Species]

For reasons outlined previously in this section, hypoxia is likely they greatest threat to juvenile spot. Spot tend to do well in warm waters, so increased temperatures from climate change are not an immediate concern; however, other impacts of climate change—e.g., changes in precipitation and subsequently salinity (Schaffler et al. 2013)—are not well understood or forecasted.

Unknowns and Uncertainties

Section IV. Recommendations for Habitat Management and Research

Habitat Management Recommendations

- Egg Stage: Spot eggs exist in offshore habitats for a short time in winter and likely have no interactions with other fishery activities. It is not currently thought that any management actions are needed to modify habitat or survival of spot eggs.
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Habitat Research Recommendations

- Identify critical habitat
- Egg Stage: Investigations into cyclonic eddies and other offshore distributional processes is an active area of fisheries research (Govoni and Spach 1999; Govoni et al. 2013). Although threats to spot eggs (and the eggs of other coastal species with offshore, winter-spawned stages) are likely minimal or non-existent, continued efforts into understanding these large-scale processes will likely be informative toward understanding the distribution of subsequent life stages.
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From the Omnibus Amendment to the ISFMP for Spanish Mackerel, Spot, and Spotted Seatrout (2012): *A periodic review should be conducted of the data resulting from the studies listed in Table 17 (page 136 of Omnibus Amendment to the ISFMP for Spanish Mackerel, Spot, and Spotted Seatrout). Particular attention should be directed toward what these data may indicate regarding habitat utilization and habitat condition (environmental parameters). A list of existing* *state and federal programs generating environmental data such as sediment characterization, contaminant analysis, and habitat coverage (marsh grass, oyster beds, SAV) should also be produced and those programs polled on a similar basis. Habitats utilized by this suite of species range from the fresh water dividing line out to, and likely beyond, the shelf break. Thus, virtually any study generating environmental data from estuarine or coastal ocean systems could be of value.*

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CHAPTER 6: Spotted Seatrout

Updated research for life stages.

Populated with text from the Omnibus Amendment to the ISFMP for Spanish Mackerel, Spot, and Spotted Seatrout (2012)

Section I. General Description of Habitat

Overall, one issue with spotted seatrout is that are comprised of unique spatial populations, generally associated with an estuary. Little mixing goes on outside of adjacent estuaries. This means that it is not always safe to project the findings of one subpopulation onto the whole species, and this concern is amplified by the number of studies in the Gulf of Mexico or areas not comparable to the US Southeast Atlantic. For example, Powell (2003 and Powell et al. 2003) presents good information on inferred spawning habitat and egg and larval distribution of spotted seatrout in Florida Bay. Florida Bay is a shallow, subtropical, oligohaline estuary without lunar tides, and considering that the spotted seatrout inhabiting this area are a unique subpopulation, it makes sense to limit the inference from a population like this onto both a different genetic and morphological stock in the Carolinas that inhabits a very different type of estuary (and this point is brought home in Smith et al. 2008 with the growth differences they found among subpopulations). Another example is the work with hypersaline conditions in Texas estuaries that are less common on the east coast. Work suggests salinity tolerances might be genetic, seriously casting doubt on how useful the results might be when applied to a Chesapeake Bay population, for example. Also, Kupschus 2003 and 2004 presents interesting habitat suitability work, but again, largely based in Florida and on Gulf of Mexico fish. The level of detail is what would be ideal for a habitat document, but the results do not match what little has been reported in the Carolinas and Chesapeake Bay, for example, so we know right away that inference should be limited.

Commented [SM3]: This is a more thought-out version of my comment above. Spotted seatrout are a great example of how inference and projection should be cautious.
Also, I know this isn't background, but the general habitat description in the provided chapter text wasn't quite in agreement with what I found. Actually, it was a little to generalized!

Part A. Spawning Habitat

Geographic and Temporal Patterns of Migration

Many age-1 spotted seatrout mature (L_{50}=292 for females; Ihde 2000) and all are mature by age-2. Consistent with the other life stages, spotted seatrout are generally restricted to their natal estuary (and adapted to their home estuary; Kucera et al. 2002) and for spawning adults this means that spawning takes place often in the lower reaches of the estuary or nearshore ocean just outside inlets.

Spawning seasons vary throughout the species range, and tend to lengthen as a function of warmer water. For example, spawning in Florida Bay has been reported to run from at least March to October (Powell 2003), while spawning in South Carolina is restricted from late April to early September (Roumillat and Brouwer 2004), and may not begin until May in North Carolina (Luczkovich et al. 2008) and the Chesapeake Bay (Smith et al. 2008). Specific estuarine locations of spawning are not well documents—particular in Atlantic estuaries—although Luczkovich et al. (2008) recorded more spawning-associated calls near Bay River (western Pamlico Sound) than near Ocracoke Inlet (eastern Pamlico Sound). It is also worth mentioning that many of the environmental variables reported by Luczkovich et al. (2008) are in contrast with spawning habitat descriptions reported by Holt and others working in the Gulf of Mexico.

Salinity

Based on work in the Gulf of Mexico, Kucera et al. (2002) found differing egg characteristics from different Texas bays. Decreasing salinity resulted in increasing size and wet weight of eggs with the opposite true for increasing salinity. Eggs from spawners native to high salinity estuaries spawned at 20ppt were not positively buoyant and died. Although it is difficult to generalize anything broadly applicable from this study, it does suggest that spawning salinity may be a locally-adapted trait.

Less work has reported on spawning salinities in the Atlantic, though Luczkovich et al. (2008) report spotted seatrout spawning-related drumming to take place in bottom salinities averaging 11.8 ppt (range 7.1–26.9 ppt), which is considerably less saline than reports from the Gulf of Mexico, but may also reflect the habitats investigated and not a uniform distribution of available salinities.

Substrate

It is unclear if spawning habitats are shared with adult habitats, and if so, what substrate preferences are. However, as eggs are pelagic, it is likely that substrate is less important than other environmental variables (such as temperature, salinity, tide, etc.).

Temperature

Spawning temperatures appear to be consistently high among all reports. For example, Louisiana spawning aggregations were highly associated with temperature 29.7 ± 0.31°C (2 standard errors; Saucier and Baltz 1993), with Brown-Peterson et al. (1988) proposing a critical minimum spawning temperature of 23°C. Others have suggested minimums of 25.6°C (Tabb 1966) and 26.3°C (Rutherford et al. 1989). Similarly in the Atlantic, spotted seatrout did not drum below 23°C (but one outlier), with most drumming occurring between 25–30°C (Luczkovich et al. 2008). Hatch dates in the Chesapeake Bay have been dated to early May, yet it remains unclear if this northern distributional population has a lower spawning temperature tolerance.

Dissolved Oxygen

As with other life stages, DO has not been widely investigated or reported for spawning adults. Despite this paucity of data, the hydroacoustic results suggests that hypoxia did not limit spotted seatrout sound production; drumming has been recorded at dissolved oxygen levels as low as 0.05 mg/L (mean 6.1 mg/L, range 0.05–9.73 mg/L; Luczkovich et al. 2008)

Feeding Behavior

Although it is unknown whether spotted seatrout feed during active spawning periods, their protracted spawning season suggests that they do feed during the spawning season, and feeding patterns likely reflect the same as adult spotted seatrout. They do not appreciably change habitats (they often remain in estuaries) to suggest that they forage on a different prey item.

Competition and Predation

No studies of competition or predation of spotted seatrout were found.

Part B. Egg Habitat

Spotted seatrout larvae use tidal flows to migrate into and within estuaries (Perret et al. 1980) where they settle in seagrass beds, shallow bays, and backwater creeks (McMichael and Peters 1989).

Geographic and Temporal Patterns of Migration

Along the Atlantic coast, spotted seatrout likely spawn in a variety of estuarine habitats. In a review of spotted seatrout, Johnson and Seaman (1986) report spawning habitat (and thus egg habitats) to range from non-tidal portions of estuarine tributaries, to outside of estuaries. Because eggs hatch 16–22h after fertilization between (25–27°C; Holt et al. 1985), the egg phase is relatively short in duration.

Salinity

Preferred salinities of spotted seatrout eggs are unknown, and likely varies as a reflection of spawning habitat. For example, Taniguchi (1981) reported from lab work an optimum salinity for hatching to be 28.1ppt (from examining 7 different salinities ranging 18.6–37.5ppt, but only reported in an abstract). Studies cited within Johnson and Seaman (1986) report spawning salinities to be similarly high (30–35ppt), while Luczkovich et al. (2008) found significant spotted seatrout drumming (a behavior characteristic of spanning) to take place in relatively low salinity waters. (11.8ppt bottom salinity, range 7.1–26.9 ppt).

Commented [SM4]: Several of the studies in this report were unavailable, yet this is a US FWS species document so I still wanted to take advantage of it and cite the information when possible.

Substrate

Due to the relatively short duration of spotted seatrout egg phase and the neutral buoyancy needed to move eggs and provide oxygen, substrate is likely not an important habitat characteristic for this species.

Temperature

Preferred temperatures of spotted seatrout eggs vary. Using eggs from Texas fish, Fable et al. (1976) reared eggs at 25°C that hatched 16–20 hours after fertilization (15hrs at 27°C and 21hrs at 23°C in other experiments). Also examining Texas fish, Gray et al. (1991) reported hatching success in treatments of 30–70ppt and 20, 23, 26, 29, 32°C. 26°C had highest hatching success at higher salinities; 23°C had high hatch success at 30ppt, but eggs did not hatch above 50ppt. Finally, Taniguchi (1981) reported optimum temperature for hatching to be 28°C (from 3 different temperature treatments ranging 24–32°C). While general trends may be applied to Atlantic stocks of spotted seatrout, these results should be used cautiously as they are based not only on artificial conditions (controlled laboratories), but using genetically different stocks that have adapted to different temperature and salinity regimes that exists in the Gulf of Mexico.

Dissolved Oxygen

No work has been conducted or reported having to do with dissolved oxygen and spotted seatrout eggs. Because eggs spawned in low salinities become demersal and die, it is accepted that minimally normoxic conditions are required for adequate egg development.

Feeding Behavior

Spotted seatrout eggs subsist entirely off the yolk sac prior to hatch.

Competition and Predation

Spotted seatrout eggs likely do not enter into any meaningful ecological competition, as their habitat demands are basic (and largely met by the oceanic or estuarine conditions). Predation of eggs undoubtedly occurs by a variety of oceanic and estuarine consumers.

Part C. Larval Habitat

Geographic and Temporal Patterns of Migration

Vertical distribution of larval spotted seatrout in the water column is variously reported. In the Gulf of Mexico, Holt and Holt (2000) describe the vertical distribution of seatrout to be most fish on the bottom during the day and similar numbers on bottom and surface at night, suggesting vertical migration. Contrary to this finding was Lyczkowski-Schultz and Steen (1991), who found the opposite. Likely both studies are an accurate reflection of what the authors sampled, but that patterns of vertical distribution may be influenced by spatial or temporal effects not included in the studies. In the Chesapeake Bay, post-settlement, late larvae are obligate seagrass residents in meso- and polyhaline areas (Dorval 2003 in Jones 2013).

Salinity

Spotted seatrout are considered among the more euryhaline of larval sciaenid, as Rutherford et al. (1989) could only collect spotted seatrout from 8–40ppt (mean 33.2 ± 1.7ppt), which, along with other work (mainly in the Gulf of Mexico, see Banks et al. 1991) establishes high tolerances of salinity and mortality at lower salinities. Tabb (1966) particularly notes that while the overall tolerance range may be wide, abrupt changes in salinity—such are from freshwater inflow resulting from precipitation—renders fish vulnerable. In the Gulf of Mexico, larvae have been collected in salinities ranging from 15–50ppt, but most at salinities >24ppt, with the same investigators concluding that low salinities reduce survival of larval spotted seatrout (Holt and Holt 2003).

Commented [SM5]: though it is not clear what age/stage the fish were and what vulnerable means, and this full reference was unavailable

Substrate

Spotted seatrout larvae settle on a variety of substrates, though the literature notes a preference for seagrass habitats when available. In the Atlantic, the primary support for this comes from recent work in the Chesapeake Bay (reported in Dorval 2003; with general seagrass habitat more fully discussed in Jones 2013). In estuaries and areas lacking submerged aquatic vegetation, such as much of South Carolina, Georgia, and parts of North Carolina, larval spotted seatrout have been collected in shallow marsh habitats (Wenner et al. 1990 and citations therein).

Temperature

Larval spotted seatrout likely tolerate a wide range of temperatures, as optimum temperatures have been reported from South Florida to be 23–33°C (Taniguchi 1981). Similarly, Powell (2003) collected larvae in Florida Bay between temperatures 20–35°C (most between 26–33°C). These temperature are likely not a distribution-wide description of conditions larval spotted seatrout experience, as hatch dates in the Chesapeake Bay have been dated to early May (Smith et al. 2008), a time at which temperatures are unlikely to fall in the ranges reported in warmer, more southerly studies.

Dissolved Oxygen

To date, no studies of dissolved oxygen requirements for larval spotted seatrout have been reported.

Commented [SM6]: I find this odd as DO has been extensively examined for other sciaenids that are even less estuarine dependent. Spotted seatrout are reliant upon estuaries and tidal creeks where hypoxia is often present. Then again, the amount of work on weakfish vs spotted seatrout is amazingly different.

Feeding Behavior

The overall pattern of feeding is likely an effect of prey availability in specific estuaries (i.e., habitats), but larval feeding is dominated by planktivorous and copepod prey items. From wild spotted seatrout larvae in Texas waters, calanoid copepods and bivalve larvae were the most important food items with gastropod veligers and copepod nauplii present (Holt and Holt 2000). Incidence of food and gut fullness was relatively high (only 17% with empty guts), though McMichael and Peters (1989) reported 85% of larval seatrout with empty guts.

Competition and Predation

Explicit studies of competitors and predators is lacking; however, larvae of other sciaenids and estuarine species likely compete for similar planktonic prey items. And consistent with other predators of larval sciaenids, gelatinous predators and larger fish are likely the dominant predators of larval spotted seatrout.

Part D. Juvenile Habitat

Geographic and Temporal Patterns of Migration

Throughout their range, juvenile spotted seatrout are most often associated with seagrass habitats or submerged aquatic vegetation. This is certainly true in the Gulf of Mexico (Rooker et al. 1998) and in Florida Bay, where spotted seatrout abundance and distribution has been linked to seagrass communities (measured by biomass, density, and species composition of seagrasses; Chester and Thayer 1990). In the Florida Bay study, temperature and salinity were relatively constant among sampled areas, with spotted seatrout captured in basins more than channels. In Mississippi waters, strong evidence supports fine-scale site fidelity; juvenile spotted seatrout from 9 coastal regions could be distinguished using 7 otolith chemistry variables, and regions were only an average of 25km apart (Comyns et al. 2008).

In the Atlantic, seagrass beds are likely important (Jones 2013), but surprisingly few studies report on this habitat type, and many are of short duration, limited temporally, or of only a single species. Chesapeake Bay juvenile spotted seatrout are obligate seagrass residents in meso and polyhaline areas (Dorval 2007; Jones 2013). And those seagrass beds (or regions of Chesapeake Bay) provide different conditions, according to Smith (2008)—who found different growth rates in eastern, central, and western bay sites depending on precipitation and freshwater flow into the bay (higher salinities tended to growth fastest). These site-specific differences have also been linked to otolith chemical composition to distinguish fine-scale seagrass bed habitat in Chesapeake Bay juvenile spotted seatrout (Dorval et al. 2005). (Although chemical composition varied between study years, it also varied among sites.) No studies of juvenile spotted seatrout in the Carolinas or Georgia were found.

Salinity

The majority of studies involving juvenile spotted seatrout provide varying ranges of tolerated salinities, typically with mean values between 15–25ppt. No explicit experiments or field work has examined salinity independent of other habitat variables, though decreasing growth in lower salinities has been reported. Spotted seatrout were the only one of five common coastal fish that grew slower during high river discharge years in Florida (Gulf of Mexico waters; Purtlebaugh and Allen 2010), and in the Chesapeake Bay, drought years have been linked to increases in growth (Smith et al. 2008). It is unclear what the mechanism behind this growth pattern is, though some have hypothesized that prolonged freshwater conditions or low salinity may increase osmoregulatory stress and compromise growth (Whitfield and Harrison 2003), or that reduced freshwater inputs reduce turbidity and improve foraging (Smith et al. 2008).

Substrate

As discussed in the Geographic and Migration Patterns section above, juvenile spotted seatrout prefer seagrass (submerged aquatic vegetation), but using shallow tidal salt marsh habitats in South Carolina and elsewhere in areas without submerged aquatic vegetation. In Florida Bay, juvenile spotted seatrout were most often captured where seagrass density and species diversity highest were (Chester and Thayer 1990). Based on an extensive study of seagrass habitat in the Chesapeake Bay, Schaffler et al. (2013) reported that spotted seatrout occurred in their study in low frequency (1.2%) but with relatively high percent occupancy (24.4%) of seagrass habitats.

Temperature

Temperature requirements—particularly minimum temperatures in the northern distributional limits of the species—is an area of active research, but with no published results. Based on work in South Carolina, temperatures < 5°C are considered cause for concern as mortality begins to become a serious threat (Anweiler et al. 2014). Experimenting with both the chronic lethal method (i.e., constantly reducing temperatures) and acclimated chronic exposure (duration of time at one low temperature), juvenile spotted seatrout lost equilibrium at 3.57 ± 0.24°C and experienced mortality at 3.08 ± 0.31°C in the chronic lethal method experiments, while 4.25°C (compared to 5.25°C) resulted in 91% mortality (compared to 4%) in the acclimated chronic exposure tests.

Commented [SM7]: This work has been done by NCSU, and know the folks doing it, but the dissertation and papers won't be out for at least a few months.

Dissolved Oxygen

To date, no studies of dissolved oxygen requirements for larval spotted seatrout have been reported.

Feeding Behavior

Juvenile spotted seatrout have moved past focusing on planktonic prey items with smaller juveniles eating mysids and caridean shrimp and larger juveniles eating penaeid shrimp and fish (Johnson and Seaman 1986 and citations therein; Fahay and Able 2010).

Competition and Predation

Explicit studies of competitors and predators is lacking; however, juvenile spotted seatrout and other juvenile sciaenids compete for space in upper-estuary habitats, and food in years of limited prey production. However, these are generalities and not based on specific studies of spotted seatrout. It is more certain that juvenile spotted seatrout are preyed upon by larger fish, such as striped bass (*Morone saxatilis*), Atlantic Croaker (*Micropogonias undulatus*), Atlantic Tarpon (*Megalops atlanticus*), and Barracuda (*Sphyraena barracuda*; Mercer 1984 in Able and Fahay 2010).

Part E. Adult Habitat

Adult diets are somewhat different from that of juveniles although the importance of food items in the water column remains. As juvenile spotted seatrout grow (greater than 30 mm in length), the dominant prey shifts to penaeid and palaemonid shrimps, which remain important in the diet of adults (Daniel 1988; McMichael and Peters 1989). As adult spotted seatrout increase in size, pelagic fishes and penaeid shrimps become increasingly important in their diet (Lorio and Schafer 1966; ASMFC 1984; Mercer 1984; Daniel 1988). Diet analysis of spotted seatrout in the lower Cape Fear River, North Carolina, revealed that Atlantic menhaden and brown shrimp are the dominant prey items of spotted seatrout during the summer and fall, and other important prey species included pinfish, spot, and striped mullet, indicating that spotted seatrout are mainly piscivorous after reaching age 1 (Tayloe and Scharf 2006).

Geographic and Temporal Patterns of Migration

The overwhelming finding regarding adult spotted seatrout geographic patterns is the limited movement that most individuals exhibit. In Florida’s Gulf of Mexico waters 9cm–72cm TL fish were tagged with 95% of recaptures occurring <30 miles from tag location (Iversen and Tabb 1962). More recently, Hendon et al. (2002) reported similar findings in that 92% of recaptured spotted seatrout moved <10km, 82% moved <3 km, and <15km movement characterized 82% of all long term (>26wk) recaptures.

In the Atlantic, Music (1981) tagged >2000 “creel-sized” spotted seatrout and recorded 15% return rate. Again, the vast majority of recaptures were within the same estuary (mean distance traveled = 8.9km), though there was some evidence of movement in and out of open sounds from creeks and rivers in fall and winter, and to beach habitat in spring and summer.

Of course issues with tagging studies exists, such location of effort and time at-large, can confound results. While some of this may take place in spotted seatrout studies, an important additional line of evidence comes from recent genetic work in the SE Atlantic. An isolation-by-distance gene flow pattern has been reported across the Atlantic coast, with distant estuaries (>300 km apart) showing significant genetic differentiation (O’Donnell et al. 2014), though even adjacent estuaries show genetic gradients. The study also notes that New River, NC acts as an integration area for spotted seatrout, north and south of which lie the greatest genetic differences.

One important aspect of adult movement that differs from the year-round estuarine-specific result is the movement of adult spotted seatrout in and out of the Chesapeake Bay. While movement in and out of an estuary is reported range-wide in association with feeding, spawning, and avoidance of specific temperature or salinity conditions (Lorio and Perrett 1980 in Johnson and Seaman 1986), seasonal movements out of Chesapeake Bay may be the only true ‘migration’ undertaken by any subpopulations of spotted seatrout (Mercer 1984; Wiley and Chapman 2003).

Salinity

No explicit studies of adult spotted seatrout salinity tolerance have been reported, other than reporting of salinity values as part of larger studies. As with other environmental variables, inference regarding the Atlantic population should be approached with caution because Gulf of Mexico populations may have different salinity tolerances owing to their genetic differences, and even within the Atlantic separate estuaries are home to different genetic stocks of spotted seatrout. That being said, adult spotted seatrout are likely increasingly tolerant of seawater (and less tolerant of freshwater) as witnessed from their lower-estuary and offshore occurrence.

Substrate

Adult spotted seatrout likely use a range of habitats including lower-estuary and nearshore beaches, where they have been reported. However, adult substrate preferences have not been reported and throughout their range estuarine habitats likely vary (e.g., presence or absence of submerged aquatic vegetation) making a universal substrate designation unlikely. As with juveniles, submerged aquatic vegetation is likely preferred, but limiting in many estuaries.

Temperature

Experimental work on minimum temperatures in juvenile spotted seatrout are likely extensible to adults (Anweiler et al. 2014), and as with other environmental parameters, estuarine or region specific preferences and tolerances should not be assumed to apply elsewhere.

Dissolved Oxygen

To date, no studies of dissolved oxygen requirements for larval spotted seatrout have been reported. Johnson and Seaman (1986) provide some information on oxygen requirements (not DO), although the citations were not available and should likely not be generalized.

Feeding Behavior

Adult spotted seatrout are piscivorous, with some penaeid shrimp remaining in the diet and fluctuating in association with availability. Tabb (1961) reported Indian River, FL spotted seatrout switching prey throughout the year based on prey availability, and consumed fishes include many common estuarine species (anchovies, pinfish, silverside, mullet, croaker, and others; Johnson and Seaman 1986 and references therein).

Competition and Predation

No studies of competition or predation of spotted seatrout were found.

Section II. Essential Fish Habitats and Habitat Areas of Particular Concern

Essential Fish Habitat

Identification of Habitat Areas of Particular Concern

The ASMFC lists submerged aquatic vegetation (SAV) as a Habitat Area of Particular Concern (HAPC) for spotted seatrout
(ASMFC 1984).

Commented [SM8]: I would be careful about all this talk about SAV. Spotted seatrout do use SAV much more than other sciaenids, but it seems very convenient to simply say (and easy to find general citations for) saving SAV habitat. It certainly has an impact on spotted seatrout given their preference for it; however, seagrass habitat is scarce from Georgia and north—much of the region covered by ASFMC. Yet spotted seatrout are in these habitats and find a way to persist without SAV. So while it might be a habitat preference, I think the evidence also suggests that they make do without it, and that conclusion brings into the discussion what 'essential' fish habitat is. SAV is doubtfully essential.

Environmental conditions in spawning areas may affect growth and mortality of egg and larvae, as sudden salinity reductions cause spotted seatrout eggs to sink, thus reducing dispersal and survival (Holt and Holt 2003).

Winter water temperature dynamics are of particular importance to habitat quality for spotted seatrout. Generally, spotted seatrout overwinter in estuaries, only moving to deeper channels or to nearshore ocean habitats in response to water temperatures below 10°C (Tabb 1966; ASMFC 1984). Sudden cold snaps have been found to stun and kill large numbers of spotted seatrout in estuarine habitats during winter (Tabb 1966; Perret et al. 1980; ASMFC 1984; Mercer 1984). These large mortality events are often associated with rapid declines (less than 12 h) in temperature, which numb fish before they can escape to warmer waters (Tabb 1958, 1966). It should be noted that cold stun events appear to have a large influence on spotted seatrout population dynamics, but it is difficult to quantify increases in mortality associated with these events. Periodic increases in mortality associated with cold stuns should still be considered when implementing management measures as they are likely to continue to occur on a periodic basis and are largely unpredictable (NCDMF 2010).

Commented [SM9]: This is being completed in NC and should be well quantified by 2015.

Present Condition of Habitat Areas of Particular Concern

By nature, the extent of SAV coverage tends to fluctuate on a scale of days to decades, depending on species and physical conditions (Fonseca et al. 1998). Globally, SAV habitat is declining. Rapid, large-scale SAV losses have been observed in the European Mediterranean, Japan, Chesapeake Bay, Florida Bay, and Australia (Orth et al. 2006). While threats to the stability of SAV health and distribution are many, water quality degradation, including nutrient enrichment and sediment loading, is the greatest threat to SAV (Orth et al. 2006). Nutrient and sediment loading into the water column can be traced to point source discharges, nonpoint source pollution, and the resuspension of bottom sediments. The impacts from the associated nutrient enrichment and sediment loading, such as increased turbidity, increased epiphytic loads, and sedimentation, and increased concentrations of toxic hydrogen sulfide directly reduce SAV growth, survival, and production (Dennison et al. 1993; Fonseca et al. 1998; SAFMC 1998). Effects of eutrophication are generally most severe in sheltered, low flow areas with concentrated nutrient loads and large temperature fluctuations (Burkholder et al. 1994).

Once SAV habitat is lost, the associated sediments are destabilized which can result in accelerated shoreline erosion and increased turbidity. These are conditions that are not favorable to SAV recolonization and expansion in the affected area. SAV in adjacent areas may also be impacted by the resulting increase of turbidity in surrounding habitats, thus increasing the total area affected (Durako 1994; Fonseca 1996). Losses of SAV on much larger scales are particularly problematic because the rate of SAV recovery though propagation, recolonization, etc. is often much slower than the rate of SAV loss (Fonseca et al. 1998). Nevertheless, recovery of SAV habitat may be possible with improvements to water quality as evidenced by the net gain of SAV acreage in Tampa Bay, Florida and Hervey Bay, Australia following stricter water quality standards (Orth et al. 2006).

Actions associated with human water use also threaten SAV abundance and coverage. Dredging for navigational purposes, marinas, or infrastructure can directly impact SAV through large-scale removal or destruction of existing grass beds. Docks constructed over SAV and the associated shading can lead to the gradual loss of SAV both beneath and in a perimeter adjacent to the docking structure (Loflin 1995; Shafer 1999; Florida Department of Environmental Protection, unpub. data). In addition to the impacts of shoreline development and dredging on SAV, the associated increase in boating activity can lead to increased prop scarring through vegetated areas. The propeller cuts leaves, shoots, and roots structures and creates a narrow trench through the sediment. Recovery of SAV from prop scarring can take in upwards of 10 years, depending on SAV species and local conditions (Zieman 1976). Wakes associated with the increase in boating activity can lead to the destabilization of sediments, which, in turn, can increase turbidity, thus impacting SAV growth potential.

Use of bottom disturbing fishing gears also have the potential to damage or destroy SAV. Although the damage from each gear varies in severity, shearing of leaves and stems, and uprooting whole plants are the most common impacts of bottom disturbing gears (ASMFC 2000). Shearing of leaves and stems does not necessarily result in mortality of SAV, but in general, productivity is reduced (ASMFC 2000). Gears that result in belowground disturbance may cause total loss of SAV and require months to years for the affected area to recover.

A newly emerging threat to SAV is the potential impacts of global climate change on this sensitive habitat. While climate change has occurred throughout history, the rate at which sea surface temperature, sea-level, and CO2 concentrations are increasing is much faster than experienced in the last 100 million years (Orth et al. 2006). These changes may be occurring at a rate too fast to allow SAV species to adapt. This leads to the potential for further large-scale losses of SAV habitat globally. If SAV is indeed able to adapt to the pace of climate change, shoreline stabilization projects in many coastal areas impede the shoreward migration of SAV necessitated by rising sea-level (Orth et al. 2006). Additionally, the increased frequency and intensity of coastal storms and hurricanes, and the associated delivery of freshwater, nutrients, and sediments, threaten to further degrade water quality in estuaries and coastal rivers, thus reducing SAV health and potential distributional extent (Scavia et al. 2002; Orth et al. 2006).

Section II. Threats and Uncertainties

Significant Environmental, Temporal, and Spatial Factors Affecting Distribution of [Species]

Unknowns and Uncertainties

Section IV. Recommendations for Habitat Management and Research

Habitat Management Recommendations

Habitat Research Recommendations

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CHAPTER 7: Weakfish

Populated from Amendment 4 to the Weakfish FMP (2002)

Section I. General Description of Habitat

Weakfish are another sciaenid species that uses a variety of coastal and estuarine habitats throughout their life. Although spawning may take place closer to estuaries or in lower estuaries (as opposed to offshore), larval weakfish recruit to upper estuary habitats and move down estuary as they grow. Much work has been done on juvenile weakfish, particularly with respect to hypoxia, and like other sciaenids, weakfish exhibit a complex relationship with dissolved oxygen concentrations. Adults often move out of estuaries and spawn in nearshore habitats. Unlike other sciaenids, weakfish have proven interesting with respect to natal homing behaviors that they exhibit.

Part A. Spawning Habitat

Geographic and Temporal Patterns of Migration

The vast majority of age-1 weakfish are mature (Lowerre-Barbieri et al. 1996a; Nye and Targett 2008) and participate in spawning behaviors that typically take place beginning late winter in the south and which progress north with the spring. Spawning typically peaks in May and June, and ends in the late summer, though temporal variability in eggs and larvae have been observed that suggest either multiple spawning peaks (Goshorn and Epifanio 1991) or an annual shift in peaks (Lowerre-Barbieri et al. 1996b). Regardless of the variability, weakfish are considered to have a long spawning period consisting of several months in most locations, with multiple reports of spawning (inferred from drumming) taking place in the evening (Connaughton and Taylor 1995; Luczkovich et al. 2008).

Spawning activities typically take place near the coast or within estuaries, many of which are natal estuaries (or adjacent estuaries; Thorrold et al. 1998; 2001). In Delaware Bay, inshore, midwater, and offshore sites (all <6km from shore) all reported spawning-associated drumming from mid-May to late-July (Connaughton and Taylor 1995). The drumming suggested large spawning aggregations in shallow waters earlier in the spawning season, with midwater and offshore drumming increasing later in the spawning season. It was hypothesized that the spawning aggregates were not just moving as a function of time, but as a function of increasing inshore temperatures, and that spawning may have continued past July in deeper waters than the study examined.

As referenced above, in the mid-Atlantic Bight spawning takes place from May to mid-July, while a longer spawning period in North Carolina begins in March and continues to September (Merriner 1976). This has led to clinal variability in life histories and reproduction (Shepherd and Grimes 1984). Weakfish spawning in southern locations live shorter lives and reproduce at smaller sizes compared to weakfish living in northern locations. Shepherd and Grimes (1984) interpret this as ‘bet hedging’ (Stearns 1976) against cold spring waters that prevent weakfish egg hatching. That is, northern weakfish have longer lives and more annual reproductive events because northern bays are more temperature variable, where as southern bays are warm enough to insure hatching (but also noting roughly equivalent lifetime reproductive potential for both extremes). This evidence for unique spatial life histories combined with the strong evidence for natal homing suggests that while habitat for spawning and other life stages may be variable, some spatial structuring exists, and estuary-specific habitat use and preference may be more important than typically considered at the population-level.

Salinity

Lower estuary and coastal spawning habitats experience moderate to high salinities. No studies have explicitly investigated salinity in relation to spawning habitat; however some studies have reported salinity values during inferred spawning events. Luczkovich et al. (1999), inferring spawning from hydroacoustic surveys, reported mean salinity to be 28.8 ppt (range 15.1–34.7 ppt). This study was somewhat limited spatially and temporally, and more expansive follow-up work reported that weakfish were commonly heard in higher salinity habitats (mean 15.4 ppt, range 7.8–28.3 ppt). (Note here that salinites were lower than the previous study, but higher among the greater number of sites examined in the 2008 study.)

Substrate

Although depth is considered an important spawning habitat variable (Luczkovich et al. 2008), no studies report on spawning habitat substrate. Additionally, weakfish eggs are pelagic and thus substrate and bottom features are considered minimally important after spawning.

Temperature

Photoperiod and temperature thought to drive seasonal maturation (Epifanio et al. 1988), along with the hypothesized avoidance of cooler spring temperatures that pose a mortality threat to larval and juvenile weakfish (Shepherd and Grimes 1984). More directly, Luczkovich et al. (1999) in a limited study reported weakfish purring in a mean temperature of 20.7°C (range 19.1–22.6°C); a more expanded study reported bottom temperatures associated with weakfish calls to average 25.3°C (range 17–31°C; Luczkovich et al. 2008).

Commented [SM10]: This is a microcosm of the issue that has arisen with all of these sciaenids. They are distributed all over the coast, in and out of estuaries, they eat all kinds of stuff, and by many accounts are generalizable. Yet when someone tries to study them, they end up with results that are influenced by the spatial and temporal aspects of the study, and this limits the inference possible from the study. So we end up with generalized habitat features that aren't that useful at small scales, and small-scale data that don't scale up…

Dissolved Oxygen

Dissolved oxygen is not well reported in adult and spawning weakfish, and based on spawning locations (deep estuaries and nearshore) low DO and hypoxic conditions are likely rare. Luczkovich et al. (2008) did measure bottom and surface DO and reported means of 7.9 and 7.6, respectively. In the same study, only one sonobuoy reported any drumming noises at <4.0 mg/L DO, although other sciaenids (spotted seatrout and silver perch) both exhibited spawning-associated noises at low DO and even hypoxic conditions.

Feeding Behavior

No studies have reported on the feeding habits of spawning weakfish, though it might be safely inferred that adult feeding habits apply to spawners, particularly because the duration spawning season suggests that spawning is integrated into their adult lives, rather than a small, discrete period that may necessitate a different foraging strategy.

Competition and Predation

No studies have reported on competition or predation of spawning weakfish, though it might be safely inferred that adult competition and predation descriptions apply to spawners, particularly because the duration spawning season suggests that spawning is integrated into their adult lives, rather than a small, discrete period that may necessitate a different behavioral strategy.

Part B. Egg Habitat

Nursery habitats are those areas in which larval weakfish reside or migrate after hatching until they reach sexual maturity (90% by age 1, 100% by age 2). These areas include the nearshore waters as well as the bays, estuaries, and sounds to which they are transported by currents or in which they hatch.

Geographic and Temporal Patterns of Migration

Mature weakfish spawn in the nearshore ocean and lower reaches of large east coast estuaries. Egg hatching occurs about 36–40 hours post-fertilization (Welsh and Breder 1923) at 20–21°C. Spawning begins in the southern region of the distribution (e.g., North Carolina) early in the spring (March; Merriner 1976) and with time progresses north in bays and estuaries. Because spawning can continue well into the summer (July in the Mid-Atlantic Bight; Berrien and Sibunka 1999) and because some estuaries have reported two peaks in spawning (Delaware Bay: Thomas 1971; Goshorn and Epifanio 1991), it is likely that weakfish eggs experience a range of conditions, and some local adaptation may influence differences in latitudinal environments. Additionally, Berrien et al. (1978) report weakfish larvae occurring from nearshore waters to 70km offshore, suggesting that the precedent egg stage may be found over a wide geographic area that extends away from the coast.

Salinity

Olney (1983) noted a distinct polyhaline distribution of sciaenid eggs, with high concentrations at the mouth of the Chesapeake Bay. Although he was not able to identify the eggs to the species level, the large number of eggs collected and the timing of collection strongly suggest that weakfish eggs were present, if not a substantial amount of the sample. Additionally, while he did not examine all regions of the Chesapeake Bay (e.g., the upper Bay), his focus and conclusions made from work in the lower bay should be reasonable based on the accepted ontogeny of weakfish. Olney (1983) reported that sampling across a range of salinities (11–31 ppt) resulted in 84% of sciaenid eggs collected in salinities >26 ppt. The Chesapeake Bay Weakfish and Spotted Seatrout Fishery Management Plan (Chesapeake Bay Program 1990) reports fertilized eggs collected between 12.1 and 31.3 ppt, but with no citation or reference to specific location or amount.

Substrate

Like many marine fish eggs, weakfish eggs are spherical, buoyant, and have a relatively short phase (compared to other life stages). The entire egg phase takes place in the pelagic zone of nearshore or lower estuarine waters, and thus substrate is not likely encountered.

Temperature

Minimum temperature is likely the main driver of weakfish reproduction and thus a necessary condition for egg development. Harmic (1958) reported a range of 12–16°C necessary for

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successful hatching; however, weakfish eggs have been collected across a range of temperatures (17–26.5°C; Chesapeake Bay Program 1990), which likely reflects their broad geographic occurrence.

Dissolved Oxygen

Dissolved oxygen is probably not an issue for short-lived weakfish eggs that remain buoyant and pelagic, and thus out of hypoxic and anoxic zones. However, Harmic (1958) reported reduced hatching success at DO <4.3 mg/L.

Feeding Behavior

Weakfish eggs subsist entirely off the yolk sac prior to hatch.

Competition and Predation

Weakfish eggs likely do not enter into any meaningful ecological competition, as their habitat demands are basic (and largely met by the offshore conditions). Predation of eggs undoubtedly occurs but has not been well studied or reported. Although potentially large numbers of eggs are killed from predation, there is no initial reason to think that pelagic oceanic predators are targeting weakfish eggs over other, similar pelagic eggs.

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Part C. Larval Habitat

Nursery habitats are those areas in which larval weakfish reside or migrate after hatching until they reach sexual maturity (90% by age 1, 100% by age 2). These areas include the nearshore waters as well as the bays, estuaries, and sounds to which they are transported by currents or in which they hatch.

Geographic and Temporal Patterns of Migration

Weakfish larvae may be as distributed as any other life stage, as larvae have been reported from nearshore waters to 70km offshore (Berrien et al. 1978), as well as throughout estuaries. Wherever the eggs hatch, larvae spend approximately 3 weeks moving toward or up estuaries. In both Delaware Bay and Chesapeake Bay, larvae have been sampled throughout the estuary, suggesting relatively quick and even post-hatch dispersal, or substantial within-estuary reproduction to feed such large systems. Additionally, the protracted spawning season—taking place over months in many locations—likely keeps a constant source of larvae provided to estuarine habitats. Olney (1983) found weakfish larvae distributed throughout the lower Chesapeake Bay (he did not examine the upper bay), but cautions against inferring too much from the lower Chesapeake Bay, which may not be as characteristic as nearshore (inner continental shelf) habitats where spawning also takes place.

Larval weakfish migration has been an active area of research. In particular, two studies have looked at selective tidal stream transport. Rowe and Epifanio (1994a) report that in Delaware Bay larvae were more abundant at depth (2 and 7 m off the bottom) than at surface. They report no effect of tidal stage on yolk sac larvae, but greater abundance of post-yolksac larvae during flood tide, suggesting that post-yolksac may use selective tidal stream transport based on abundance periodicity. In a second study by the same authors (Rowe and Epifanio 1994b), they report mean larval flux to be greater during flood phase for all early and late stage larvae, but not for yolk sac larvae. Together, these two studies suggest that while yolksac larvae are passively transported as part of general sub-tidal circulation, post-yolksac larvae use selective tidal stream transport to migrate up estuaries.

Salinity

Owing to the wide distribution of weakfish larvae, a range of salinities is likely tolerated. In the lower Chesapeake Bay, Olney (1983) reported salinities of larval weakfish sampling to range from 11.2 to 31.5 over 4 years of collecting. In examining tidal stream transport of larval weakfish, Rowe and Epifanio (1994a) report salinities of migrating larvae to be 20.1–27.8 ppt over two sampling events in two years (but low variation within years). These two studies are likely a good indicator of the mean and variation around salinity values for larval fish; however, they are both studies from lower estuary (higher salinity) environments and may not reflect lower salinities that upper estuary larvae experience.

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Substrate

Larval weakfish are planktonic (Welsh and Breder 1923) and thus do not come in contact with the large variety of substrate types over which they are dispersed.

Temperature

As with salinity, both Olney (1983) and Rowe and Epifanio (1994a) provide environmental descriptors of larval habitat, but both with the caveat that larvae occur over a wide area and neither study was intended to be a comprehensive evaluation of habitat. With that in mind, both studies report similar ranges: Olney (1983) sampled larval weakfish in the Lower Chesapeake Bay over 4 years in 18.1–28.1°C and Rowe and Epifanio (1994a) report Delaware Bay temperatures of migrating larvae to be 16.8–22.9°C over two sampling events in two years (but low variation within years).

Dissolved Oxygen

Due to the relatively short larval duration, the pelagic habitat, and the migratory behaviors of weakfish larvae, it is unlikely that they encounter any habitats in which dissolved oxygen imposes a limitation or threat.

Feeding Behavior

A number of studies have investigated the feeding behaviors of larval weakfish, both in laboratory settings as well as in the field. Goshorn and Epifanio (1991) investigated size-dependent diets from weakfish larvae sampled throughout Delaware Bay. Larval weakfish began exogenous feeding 2 days post hatch at 20°C, and invertebrate eggs and tintinnids were found to be import for small weakfish larvae (< 3.5mm NL [notochord length]). Polycheate larvae were important for all size classes and dominant in weakfish >3.55mm NL. Small copepods (*Acartia tonsa*) were also important for all weakfish larvae, but dominant in at sizes > 7.55mm NL. About half of smaller weakfish larvae had an empty gut, but all larvae > 5.55mm NL contained food.

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In laboratory experiments, Pryor and Epifanio (1993) used rotifers (*Brachionus plicatilis*) and brine shrimp (*Artemia sp.*) as prey to determine that larval weakfish do not forage solely on prey size. Prey swimming speed had no effect on selection; rather, larger preys were favored when prey densities were high (100 items/L). Lower prey densities and smaller (early-stage) weakfish showed less preference for either prey type or prey size. Duffy et al. (1996) also examined the effect of prey densities on larval feeding in an experimental setting. They reported a trend of elevated growth rates with increasing prey density, both for early and late stage larvae (but all prey densities led to growth). Mortality was unrelated to prey densities (and not a function of predators because none were included), but the authors caution that depressed growth rate in the wild would lead to increased mortality, which was not reflected in their experiments.

Competition and Predation

Little work has looked at competition and predation of larval weakfish. Some competition likely takes place when a high-density larval patch settles on limited habitat; however, the wide range of settled habitats and protracted spawning season suggest that widespread competition is unlikely. Furthermore, work on natal homing (Thorrold et al. 1998; 2001) suggests that adult weakfish return to natal estuaries to spawn, thus adding a level of population structure to mitigate against widespread competition.

Foraging competition might be inferred from the studies referenced in the Feeding Behavior subsection (above), although Duffy and Epifanio (1994) present results on growth and inferred mortality of larval weakfish at differing densities. From field-based prey density of 250 items/L and regardless of larval age (early or late-stage), growth rates were depressed in high density (*n*=5000) weakfish treatments. Such depression of growth would likely increase the duration of the larval stage and thus increase overall mortality. This result is not particularly unexpected or unique for weakfish as most larval fish would expect to respond similarly to high densities; however, Duffy and Epifanio (1994) quantify important parameters, such as instantaneous growth rate and different metrics of growth (e.g., length, weight).

No studies have explicitly reported on predation of larval weakfish, although larvae are likely subject to predation by a range of estuarine predators. Cowan et al. (1992) examined hydromedusa (*Nemopsis bachei*)and ctenphore (*Mnemiopsis leidyi*) predation on black drum (and Duffy and Epifanio 1994 reference gelatinous predators), suggesting that high densities of hydrozoans could impact larval weakfish abundance.

Part C. Juvenile Habitat

Juvenile weakfish inhabit the deeper waters of bays, estuaries, and sounds, including their tributary rivers. They also use the nearshore Atlantic Ocean as a nursery area. In North Carolina and other states, they are associated with sand or sand/seagreass bottom. They feed initially on zooplankton, switching to mysid shrimp and anchovies as they grow. In Chesapeake and Delaware Bays, they migrate to the Atlantic Ocean by December.

Geographic and Temporal Patterns of Migration

The general pattern of habitat use by juvenile weakfish is estuarine-wide, but often beginning in late spring and early summer in upper estuarine habitats (or even freshwater; Massman 1954) and moving down estuary for a fall migration to nearshore habitats. A large number of investigators have explored juvenile habitat use in detail.

Delaware Bay

Able et al. (2001) found high abundance of weakfish in June throughout Deleware Bay tidal creeks, and the large numbers of fish were attributed somewhat to high recruitment. They also reported mean catch per unit effort (CPUE) for young-of-year (YOY) weakfish to be much higher in upper bay sites over lower bay sites, though the species had a transient pattern of habitat utilization. Paperno et al. (2000) also reported that juvenile weakfish recruited to all parts of Delaware Bay, but higher CPUEs were found in lower salinities, and Litvin and Weinstein (2004) used stable isotope ratios to infer and support movements down estuary and estimate estuarine organic matter in Delaware Bay weakfish. Grecay and Targett (1996) concluded that spatial differences in juvenile weakfish condition existed due to differences in fish condition around Delaware Bay; i.e., despite the wide larval distribution, differences in juvenile condition indicate some amount of site fidelity for a period of the juvenile stage.

Strong temperature and salinity interactions suggest oligohaline conditions are preferable early in the season or for earlier cohorts, which use higher temperature and lower salinity waters (Lankford and Targett 1994). Throughout the estuary, temperature differences diminish through the summer and the high energetic cost of low salinity causes the favorable conditions to shift to mesohaline estuarine regions. A tradeoff could also exist in the decision to remain in oligiohaline habitats: lower predation in oligohaline habitats may be beneficial and retain some individuals, while physicochemical conditions decline in suitability. In fact, Lankford and Targett (1994) posit this tradeoff as an explanation for the main reason why exceptions to and variations of the general down-estuary movement pattern exist (see Szedlmayer et al. 1990 for up estuary movement in Chesapeake Bay and Paperno 1991 for no evidence of movement).

Chesapeake Bay

In the York River, VA yearling and YOY juveniles were caught in spring and summer, to which Chao and Musick (1977) attributed water temperature and DO to be most important factor driving distribution. Weakfish were primarily absent in January and April sampling, sampled in high abundance in late summer and fall with yearlings returning in the spring but YOY not showing up in sampled until late summer. In and nearshore of the Chesapeake Bay a pattern of similar habitat use in early and late summer was discovered when comparing inner continental shelf and estuarine habitats, with an expected strong shift to inner continental shelf habitat use over estuary by fall (Woodland et al. 2012). This same study also reported that weakfish (presumably many juveniles) were the most abundant species of 17 common coastal species caught in the fall. Growth rates between habitats were similar, suggesting no growth advantage in either habitat, but in late summer larger fish were clearly in the inner continental shelf while smaller fish were in estuary. This is presumed to reflect the fact that early-spawned weakfish get to oceanic environments earlier that late-spawned weakfish, though by fall the difference in size classes was diminishing (Woodland et al. 2012).

Maryland Bays

Much has been claimed about the role of seagrasses as essential habitat (particularly for juvenile estuarine fish); however, Pincin et al. (2014) examined weakfish abundance in coastal Maryland bays from 1972–2009 and found no effect of sea grass (which has been increasing in the latter part of the survey). This lack of seagrass effect on fish abundance was true for several other species, and not just weakfish. The authors do suggest that habitat use is as much a function of stock-wide recruitment processes than fine-scale (i.e., microhabitat) factors.

Note: Weinstein et al. (2009) report on the possibility of overwintering juvenile YOY weakfish in Upper Delaware Bay (Christina River, DE) from late fall captures and over winter mortality in power plants. The sample sizes are relatively low and this result is contrary to the widely accepted pattern of ontogenetic down-estuary movement in the fall. The authors hypothesize a link to climate change (i.e., rising temperatures) as the reason for estuarine retention, but don't discuss specifically any mechanisms or climate data. This is certainly an interesting finding, but at the present time should be considered an exception to the range-wide habitat use and movement that has been observed.

Salinity

Juvenile weakfish salinity preferences likely increase with size and age, in accordance with the general pattern of movement from oligohaline habitats to meso- and polyhaline habitats throughout the first year of life. Salinity has been reported in some of the studies reference in the above Geographic and Migrations Patterns subsection, however salinity is not reported or examined other than as basic environmental data, and the wide values in reporting reflect the wide variety of habitats used. One specific examination of salinity was done by Lankford and Targett (1994), who found salinity effects on specific growth rates and gross growth efficiencies to be significant at 24 and 28°C treatments, and they predicted optimal salinity was 20 ppt for 40–50mm fish. Salinity effects on growth were most pronounced in the 28°C treatment, and the feeding rate was significantly higher in this treatment at 5ppt than 19ppt salinity.

Substrate

Few studies have reported on juvenile weakfish substrate preferences, and only occasionally has substrate use been included in habitat descriptions. This lack of work on substrate likely stems from two reasons: 1) temperature and salinity are thought to be the habitat variables driving juvenile weakfish distribution and migrations, and 2) given the extreme distribution of juvenile weakfish (freshwater habitats to coastal ocean habitats), it is clear that a diversity of substrate types can be associated with the juvenile stage.

Temperature

Juvenile weakfish likely tolerate a wide range of temperatures, though temperature is considered to be an important variable driving their distribution. Although temperature has been documented in a number of descriptive studies, Lankford and Targett (1994) examined temperature effects on specific growth rates and gross growth efficiencies, and found significant effects at 29 and 27°C treatments. Overall, mean feeding rates increased with increasing temperature (from experimental treatments of 20–28°C); however, it should be noted that their intent was to understand the interactions of temperature and salinity, so interpreting one variable at a time might obscure the interactive effects of these two important variables that act simultaneously in nature.

Dissolved Oxygen

A relatively large body of research has been done on the effects of dissolved oxygen levels on (juvenile) weakfish. Much of this work has come out of the University of Delaware and has been conduced in small coastal systems in Delaware. Tyler and Targett (2007), working a coastal estuary in Delaware, reported low weakfish densities in early morning (during diurnal hypoxic conditions) but relatively high weakfish densities later in the day. This study also established field-based estimates of an avoidance threshold of 2.0 mg/L, above which weakfish returned within 2 hours, suggesting upper tidal tributaries (where hypoxia is often present) represent important habitat. Following up this study, Tuzzolino (2008) found greater stomach fullness for weakfish at more hypoxia-impacted sites (in Pepper Creek, DE, the same system as Tyler and Targett 2007). Juvenile weakfish stomachs also contained more polycheates, a prey item that may indicate onset of hypoxic conditions.

Even more recently, Brady et al. (2009) examined differences between weakfish previously exposed to hypoxia and those acclimated only to DO saturation conditions. Previous hypoxia exposure was found to be a very important behavior modifier, as the swimming speeds associated with hypoxia avoidance were different between the differently acclimated fish. The 10-day hypoxia acclimation period may also be enough to eliminate the stress hormone driving the escape response (Brady et al. 2009). A lower threshold of avoidance (<1.4 mg/L DO) was later reported by Brady and Targett (2013) for hypoxia-acclimated fish, supporting the idea that not only are these fish less inclined to swim to avoid hypoxia, but that they can tolerate lower levels than fish never exposed to hypoxia.

Less work has been done on hypoxia effects on growth, although no effect of hypoxia on growth has been reported (Stierhoff et al. 2009). This same study reported avoidance of low DO (≤1 mg/L), but no preference to DO levels > 2.0mg/L, which is generally in accordance with the idea that sciaenids are relatively tolerant of hypoxia.

Feeding Behavior

Juvenile weakfish progress through a number of prey items as their (mouth) size increases, though at most stages diets can be variable (Nemerson and Able 2004). Smaller juvenile (40–84 mm) diets were examined in upper, mid and lower Delaware Bay, with gut fullness highest in mid-Bay, and lowest in the upper bay (Grecay and Targett 1996a). In all regions, mysid shrimp (*Neomysis americana*) dominated the diet. The authors hypothesized that turbid upper-Bay conditions extinguished light, which reduced visual feeding success and this growth. The authors explicitly examined this hypothesis in a laboratory setting (Grecay and Targett 1996b) and concluded that as long as some light is present, feeding is unaffected. When light was extinguished, feeding was reduced, and the effect of prey (mysid) density became the most important factor as encounter rates predicted foraging success. Bad prey years combined with turbid conditions are suggested to result in decreased growth and increase mortality for juvenile weakfish.

Larger juvenile weakfish (67–183mm) in the Chesapeake Bay diets revealed mostly bay anchovy (*Anchoa mitchelli*) and mysid shrimp (*Neomysis americana*; Chao and Musick 1977), which highlights the transition from mysids to fish (piscatory) around 60 mm TL (Thomas 1971). Lankford and Targett (1997) present an interesting foraging result of selective feeding on lower-energy mysids over higher-energy sevenspine shrimp (*Crangon septemspinosa*), but conclude that more energy was extracted from the mysids in digestion (measured from gut evacuation rates) to justify the prey preference.

Competition and Predation

Due to the wide spatial distribution and extended temporal period of recruiting juvenile weakfish, it is unlikely that any large-scale competitive factors drive the population. Annual fluctuations in recruitment and micro-scale habitat and foraging competition probably result in patches of competition and variable outcomes. Forage items are typically not limited, though in years of low prey abundance (and high turbidity; Grecay and Targett 1996b) competition may result in decreased growth rates for less fit individuals.

Juvenile weakfish are likely preyed upon opportunistically by a range of estuarine and nearshore predators (fish); however, Mancini and Able (2005) report silver perch *Bairdiella chrysoura* and bluefish *Pomatomus saltatrix* as the main documented predators. Competition and predation of juvenile weakfish is also encapsulated (and referenced previously in the Geographic and Migrations Patterns subsection) through the complex tradeoffs assumed to take place in the use of oligiohaline habitats. Large predators are typically less abundant or absent in oligotrophic, upper estuarine areas, yet as temperatures increase in summer, the interactions of temperature and salinity result in a suboptimal physicochemical environment (Lankford and Targett 1994; Lankford and Targett 1997).

Part D. Adult Habitat

Adult weakfish reside in both estuarine and nearshore Atlantic Ocean habitats. Warming of coastal waters in the spring keys migration inshore and northward from the wintering grounds to bays, estuaries and sounds. Larger fish move inshore first and tend to congregate in the northern part of the range. Catch data from commercial fisheries in Chesapeake and Delaware Bays and Pamlico Sound indicate that the larger fish are followed by smaller weakfish in summer. Shortly after their initial spring appearance, weakfish return to the larger bays and nearshore ocean to spawn. In northern areas, a greater portion of the adults spends the summer in the ocean rather than estuaries.

Weakfish form aggregations and move offshore as temperatures decline in the fall. They move generally offshore and southward. The Continental Shelf from Chesapeake Bay to Cape Lookout, North Carolina, appears to be the major wintering ground. Winter trawl data indicate that most weakfish were caught between Ocracoke Inlet and Bodie Island, NC, at depths of 18 -– 55 meters (59 – 180 feet). Some weakfish may remain in inshore waters from North Carolina southward.

Geographic and Temporal Patterns of Migration

After juvenile weakfish overwinter in offshore environments, the vast majority (>90%) mature during their second year of life (age-1). The general pattern of adult habitat use is considered to be seasonal migrations south (toward Cape Hatteras, NC) and offshore in fall and winter, and north and inshore during spring and summer (Able and Fahay 2010). Summer inshore habitats are shallow, averaging around 17m, while offshore winter habitats aver 59m, but include depths up to 159m (Able and Fahay 2010). Despite this overall pattern of adult habitat use, exceptions exist. For example, several instances occur of weakfish using bay-deep estuarine habitats and even tidal creeks (Wuenschel et al. 2013).

Off the New Jersey coast in the summer, weakfish occurred primarily inshore in shallow strata (but only looked at inshore habitats of inner continental shelf; Wuenschel et al. 2013). This particular study reported on fish sized 80–565mm TL, so some juveniles were likely included with adult fish and habitats are known to overlap. Wuenschel et al. (2013) note a high degree of similarity with bluefish in use of inshore shelf habitat during the summer. Age-1+ weakfish were also found to use an estuary in coastal New Jersey (the Navesink River) during the summer. Tagged weakfish left the estuary when temperatures were above 28°C and when freshwater discharge was low (<2 m^3/s). Smaller weakfish were more like to have longer overall residence times, although even large individuals (>400mm TL) demonstrated estuarine habitat use ≥ 40 days (with some > 60 days residence). These tagged weakfish were also found to leave the estuary when temperatures decreased below 23°C.

Also noteworthy is the otolith microchemical and isotopic work that has clearly found homing in weakfish. Thorrold et al. (1998; 2001) have studied natal origins of weakfish and compared the chemical signals in juveniles to adults and concluded that 60–81% of weakfish exhibit estuarine fidelity as adults, despite the fact that the same fish from across the eastern US were genetically panmictic.

Salinity

Adult weakfish occur primarily in nearshore or lower estuarine habitats where salinities are near full seawater. In a review of weakfish, Mercer (1989, and citations therein) report adult weakfish being collected over salinities ranging from 6.6 to 32.3 ppt. Focusing on those examples of estuarine habitat use by adults suggests that weakfish still prefer higher salinities when in estuaries in the summer; Rountree and Able (1992) sampled adults in 22–32 ppt shallow sub- and intertidal marsh creeks in New Jersey. And although salinity values are not reported in Manderson et al.’s (2014) study of summer estuarine habitat use by weakfish, it is likely that the study estuary exhibited salinities less than full seawater. As with other habitat variables, salinity is probably tolerated at variable levels reflected in the variety of inshore and nearshore habitats populated by adult weakfish.

Substrate

In accordance with the variety of habitats used by adults, specific habitat use or habitat preference in adult weakfish has not been reported. Able and Fahay (2010) report the use of sandy or muddy substrates by adults in bays and estuaries, but substrates used are likely as variable as the overall habitats in which adult weakfish are found.

Temperature

Temperature is likely a major driving in development of reproductive tissue and spawning behaviors in weakfish, though it is still an important habitat factor among resting (not reproductively active) adults. Weakfish have been reported captured in a wide range of temperatures (see Mercer 1989 for review, but sizes and ages missing from some reported data). Contemporary studies of weakfish temperature occurrence or preference are lacking, likely due to both their wide distribution and inferred tolerance for a range of temperatures, but also due to the relatively high effort in studying juvenile weakfish habitat. One recent study of adult weakfish took place in coastal waters off New Jersey, and temperature was found to be variable and without a direct, interpretable effect in the summer (Wuenschel et al. 2014). More telling, perhaps, was the movement of adult weakfish in the coastal estuary, in which temperatures exceeding 28°C and below 23°C both resulted in weakfish egress.

Dissolved Oxygen

Adult weakfish likely experience normoxic conditions, as they typically avoid the upper estuary reaches inhabited by juvenile weakfish where hypoxia is most commonly reported. Without any explicit studies of adult weakfish dissolved oxygen tolerances or preferences, such values might be estimated from the extensive body of work conducted on juvenile weakfish and dissolved oxygen. Later stage juvenile weakfish may have physiologies (and subsequent tolerances) similar to adults.

Feeding Behavior

Adult weakfish feed primarily between dawn and dusk, primarily on clupeid species, anchovies, blue crabs, and spot (Mercer 1989 and citations therein). More recent work has supported piscivory as the main adult weakfish feeding mode, but also note crustaceans, mollusks, shrimp, squid, and other common estuarine forage items (Able and Fahay 2010). Overall diets have shown to vary, but in proportion to available prey. Adult weakfish diets have been shown to be relative stable from June to October (Wuenschel et al. 2013).

Competition and Predation

Competition among adult weakfish is not well known. Silver perch and bluefish are commonly cited as the primary predators (Mancini and Able 2005), though predation of larger adults likely decreases with size and may include occasional larger coastal predators. In studying four coastal predators, only weakfish were appreciable consumed by other species, namely summer flounder and bluefish, but also cannibalistically (Wuenschel et al. 2013). The same study noted that by October summer flounder and bluefish predation was extensive (~25%), however this probably reflected the high abundance of weakfish.

Section II. Essential Fish Habitats and Habitat Areas of Particular Concern

Essential Fish Habitat

Identification of Habitat Areas of Particular Concern

There is no HAPC designation for weakfish.

Present Condition of Habitat Areas of Particular Concern

The quality of weakfish habitats has been compromised largely by impacts resulting from human activities. It is generally assumed that weakfish habitats have undergone some degree of loss and degradation; however, few studies that quantify impacts in terms of the area of habitat lost or degraded.

Loss due to water quality degradation is evident in the northeast Atlantic coast estuaries. The New York Bight is one example of an area that has regularly received deposits of contaminated dredged material, sewage sludge and industrial wastes. These deposits have contributed to oxygen depletion and the creation of large masses of anoxic waters during the summer months.

Some losses have likely occurred due to the intense coastal development that has occurred during the last several decades, although no quantification has been done. Losses have likely resulted from dredging and filling activities that have eliminated shallow water nursery habitat. Further functional losses have likely occurred due to water quality degradation resulting from point and non-point source discharges. Intensive conversion of coastal wetlands to agricultural use also is likely to have contributed to functional loss of weakfish nursery area habitat.

Other functional loss of riverine and estuarine areas may have resulted from changes in water discharge patterns resulting from withdrawals or flow regulation. Estuarine nursery areas for weakfish, as well as adult spawning and pre-spawning staging areas, may be affected by prolonged extreme conditions resulting from inland water management practices.

Power plant cooling facilities continue to impact weakfish populations. The EPA in recent rules regarding these facilities estimates that the number of total weakfish age 1 equivalents lost as a result of entrainment at all transition zone cooling water intake structures in the Delaware Bay is over 2.2 million individuals. Other threats stem from the continued alteration of freshwater flows and discharge patterns to spawning, nursery, and adult habitats in rivers and estuaries. Additional threats in the form of increased mortality resulting from placement of additional municipal water intakes in spawning and nursery areas will occur, although the impacts may be mitigated to some degree with proper screening.

Section II. Threats and Uncertainties

Significant Environmental, Temporal, and Spatial Factors Affecting Distribution of [Species]

Unknowns and Uncertainties

Section IV. Recommendations for Habitat Management and Research

Habitat Management Recommendations

Habitat Research Recommendations

- Conduct hydropohonic studies to delineate weakfish spawning habitat locations and environmental preferences (temperature, depth, substrate, etc) and enable quantification of spawning habitat.
- Compile existing data on larval and juvenile distribution from existing databases in order to obtain preliminary indications of spawning and nursery habitat location and extent.
- Document the impact of power plants and other water intakes on larval, post larval and juvenile weakfish mortality in spawning and nursery areas, and calculate the resulting impacts on adult stock size.
- Define restrictions necessary for implementation of projects in spawning and overwintering areas and develop policies on limiting development projects seasonally or spatially

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CHAPTER 8: Northern Kingfish

Section I. General Description of Habitat

Northern kingfish are found in estuaries and coastal areas from Maine to the Yucatan, Mexico (Irwin 1971) and are more common in the Mid-Atlantic Bight than in the South Atlantic Bight (Hildebrand and Schroeder, 1928; Schaefer, 1965; Ralph 1982). Northern kingfish prefer habitats in close proximity to inlets and in the ocean in depths less than 20 meters (Welsh and Breder 1923; Bearden 1963; Irwin 1971; Ralph 1982). Juvenile northern kingfish inhabit shallower waters than the adult northern kingfish and were typically found in the surfzone and rivers (Bearden 1963; Ralph 1982).

Part A. Spawning Habitat

Geographic and Temporal Patterns of Migration

Northern kingfish are thought to migrate inshore and northward from their overwintering habitats during the spring and summer while spawning is occurring (Hildebrand and Cable 1934). Fish in spawning condition have been observed from March through September based on macroscopic inspection of gonads for fish in North Carolina (Collier in prep) and from June through August based on the size distribution of young of the year fish (Welsh and Breder, 1923; Schaefer, 1965; Miller et al., 2002). Spawning is suggested to occur in the nearshore-ocean or within inlets in deep channels (Irwin 1971; Ralph 1982).

Salinity

Adult northern kingfish are thought to spawn in lower estuary and coastal habitats where the waters tend to have moderate to high salinities (Ralph 1982). Adult northern kingfish are found in higher salinity waters than juveniles (Hildebrand and Cable 1934; Irwin 1971; Ralph 1982) and juveniles are rarely found in salinities less the 20 ppt (Bearden 1963). The spawning is reported to occur on the bottom (Ralph 1982).

Substrate

The spawning habitat has not been described for northern kingfish but northern kingfish are typically found over sandy bottoms (Welsh and Breder 1923; Hildebrand and Cable 1934; Bearden 1963) with some reports of northern kingfish around oysters and hard bottom (Irwin 1971). It is expected that northern kingfish spawn over sandy or muddy bottoms in the ocean and in deeper channels.

Temperature

Northern kingfish migrate based on temperature and will remain in the lower estuary and nearshore-ocean during the spawning season. Northern kingfish have been observed in temperatures from 7.8 to 35.8 C (Irwin 1971). The temperature range is likely to vary with latitude with northern kingfish from Mid-Atlantic experiencing lower temperatures than fish inhabiting the South Atlantic and Gulf of Mexico. Temperature related fish kills have been reported in the northern part of their range during the winter which is out of the spawning time (Irwin 1971).

Dissolved Oxygen

Preferences for dissolved oxygen have not been reported for adult and spawning northern kingfish. Based on suspected spawning locations (deep estuaries and nearshore) low DO and hypoxic conditions are likely rare.

Feeding Behavior

Diets of northern kingfish were typically reported during the summer months which includes the spawning season. The diet of northern kingfish typically comprised of Penaeid shrimp, polycheate worms, and amphipods in the South Atlantic Bight (Welsh and Breder 1923; Bearden 1963) and shrimp, crabs, and squids in northern latitudes (Irwin 1971).

Competition and Predation

Competitors of northern kingfish likely include other members of sciaenid family including it congeners, southern and Gulf kingfishes, spot, Atlantic croaker, red drum, and black drum based on diet and habitat overlap (Ralph 1982). No studies have reported on competition or predation of spawning northern kingfish, though it might be safely inferred that adult competition and predation descriptions apply to spawners, particularly because the duration spawning season suggests that spawning is integrated into their adult lives, rather than a small, discrete period that may necessitate a different behavioral strategy. See Adult competition and Predation for more information on competition and predation.

Part B. Egg and Larval Habitat

The eggs of northern kingfish are buoyant and water column is the primary habitat. Eggs have been reported in the water column of the nearshore-ocean and in estuaries.

Larvae of northern kingfish are defined as kingfish less than 25 mm standard length although the size of transition is not clearly defined (Welsh and Breder 1923). It is likely the nursery habitats for northern kingfish extend from the nearshore ocean into upper reaches of estuaries due to tidal transport. The greatest concentration of larvae northern kingfish occur in the nearshore ocean and lower estuaries (Irwin 1971; Ralph 1982).

Geographic and Temporal Patterns of Migration

Mature northern kingfish spawn in the nearshore ocean and lower reaches of deep estuaries. Egg hatching occurs about 46-50 hours post-fertilization at 20–21°C (Welsh and Breder 1923). Spawning begins in the southern region of the distribution (e.g., North Carolina) early in the spring and likely begins later in the spring in northern latitudes (Irwin 1971). Eggs are likely subjected to a variety of environmental conditions due to the protracted spawning season and broad geographic distribution from Florida to Maine in euryhaline areas similar to southern kingfish (Bearden 1963).

Northern kingfish larvae may be as distributed as any other life stage, as larvae have been reported in nearshore ocean waters and throughout estuaries (Bearden 1963; Irwin 1971; Ralph 1982). Larval northern kingfish migration has had little research. It is likely the larval transport of northern kingfish is similar to the larval transport of weakfish given the general overlap in spawning season and location. See Weakfish Geographic and Temporal Patterns of Migration for more information.

Salinity

Salinity has not been reported but eggs and larvae of kingfish (some studies do not differentiate) indicate they are concentrated in the ocean near inlets and the lower parts of estuaries where salinities are higher (Ralph 1982; Flores et al. 1999; Reiss and McConaugha 1999).

Northern kingfish larvae likely tolerate a wide range of salinities based on their wide distribution but are most common in waters with salinities greater than 20 ppt similar to southern kingfish (Bearden 1963). As northern kingfish grow, they are found in higher salinity waters (Ralph 1982). Although northern kingfish larvae are distributed over a range of salinities, it is not known if rapid changes in salinity impact survival.

Substrate

Commented [ML15]: Eggs copied from weakfish

Like many marine fish eggs, northern kingfish eggs are spherical, buoyant, and have a relatively short phase (compared to other life stages). The entire egg phase takes place in the pelagic zone of nearshore or lower estuarine waters, and thus substrate is not likely encountered.

Larval northern kingfish are planktonic (Welsh and Breder 1923) and thus do not come in contact with the large variety of substrate types over which they are dispersed.

Temperature

Minimum temperature is likely the main driver of northern kingfish reproduction and thus a necessary condition for egg development. Welsh and Breder (1923) spawned northern kingfish at 20-21° C and based on average ocean temperatures for months listed as spawning times, northern kingfish likely spawn at temperatures between 18-27° C.

Based on presence of northern kingfish recruiting at different times and different locations minimum temperature is likely important factor in their distribution. Based on average ocean temperatures for months listed when juvenile northern kingfish were captured, northern kingfish are found in temperatures between 18-30° C.

Dissolved Oxygen

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Dissolved oxygen is probably not an issue for short-lived northern kingfish eggs that remain buoyant and pelagic, and thus out of hypoxic and anoxic zones.

Due to the relatively short larval duration, the pelagic habitat, and the migratory behaviors of northern kingfish larvae, it is unlikely that they encounter any habitats in which dissolved oxygen imposes a limitation or threat.

Feeding Behavior

Northern kingfish eggs subsist entirely off the yolk sac prior to hatch.

The feeding behaviors of larval northern kingfish have not been described. Additional research is needed, but the behaviors are likely similar to other sciaenids.

Competition and Predation

Northern kingfish eggs likely do not enter into any meaningful ecological competition, as their habitat demands are basic (and largely met by the offshore conditions). Predation of eggs undoubtedly occurs but has not been well studied or reported. Although potentially large numbers of eggs are killed from predation, there is no initial reason to think that pelagic oceanic predators are targeting weakfish eggs over other, similar pelagic eggs.

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No study has looked at competition and predation of larval northern kingfish but the larvae likely compete with Gulf and southern kingfishes and members of the sciaenid family including spot, Atlantic croaker, weakfish, red drum, and black drum (Ralph 1982) as well as Florida pompano and silversides in the surfzone (Bearden 1963). Some competition likely takes place when a high-density larval patch settles on limited habitat; however, the wide range of settled habitats and protracted spawning season suggest that widespread competition is unlikely.

Part C. Juvenile Habitat

Juvenile northern kingfish are kingfish general between the sizes of 25 and 150-230 mm SL. The upper size varies between sexes due to the differential size at maturity. Juvenile northern kingfish inhabit the nearshore-ocean and surfzone and the deeper waters of bays, estuaries, and sounds, including their tributary rivers. Northern kingfish were found to be summer estuarine residents of estuarine beaches based on mark recapture and length frequency (Miller et al. 2002).

Geographic and Temporal Patterns of Migration

The general pattern of habitat use by juvenile northern kingfish is estuarine-wide but often most common beginning in late spring and early summer in lower estuarine and nearshore habitats and move to deeper more saline waters in the fall (Ralph 1982; Miller et al. 2002). Northern kingfish tend to remain in localized areas throughout the summer (Miller et al. 2002).

Salinity

Juvenile northern kingfish migrate to deeper more saline waters as they get larger. By the fall most northern kingfishes migrate out of the shallow estuarine and nearshore ocean environment to the deeper ocean habitats to overwinter (Bearden 1963; Ralph 1982; Miller et al. 2002). Growth rates were compared among different habitats and no significant differences were detected indicating salinity did not impact growth rates based on one tagging/length frequency study (Miller et al. 2002). The fish tended to leave the estuarine beaches at smaller sizes than at oceanic beaches (165 TL vs 230 TL). It is not known if salinities lower than the ones observed during the study, which were all greater than 20 ppt, would impact growth and survival rates.

Substrate

Juvenile northern kingfish are typically observed over sandy sediment in shallow estuarine and surfzone environments and likely can be found over mud environments (Welsh and Breder 1923; Irwin 1971; Ralph 1982). There are reports of northern kingfish being caught over hard substrate including oyster shell (as reported in Irwin 1971; Ralph 1982).

Temperature

Juvenile northern kingfish likely tolerate a wide range of temperatures, though temperature is considered to be an important variable driving their distribution. Juvenile northern kingfish are rarely seen in temperatures below 20° C and migrate out of shallow waters in September and October (Ralph 1982; Miller et al. 2002). Juvenile northern kingfish in a tank experiment avoided temperatures above 30° C.

Dissolved Oxygen

Little has been reported on the impact of dissolved oxygen levels on juvenile northern kingfish. The lower estuary and surfzone environments may have fewer occurrences of hypoxic and anoxic events compared to upper estuarine habitats. However, northern kingfish do have a relatively fast growth rate (1.8-2.4 mm/day as juveniles, Miller et al. 2002), which could be attributed to the evelated metabolic rate of northern kingfish (Horodysky 2011).

Feeding Behavior

Juvenile northern kingfish are typically described as benthic foragers. They use their barbel to detect prey. The juvenile diet consists of nematodes, polychaete worms, mysid shrimp, penaeid shrimp, isopods, amphipods copepods, fishes, and detritus (Ralph 1982). Juvenile northern kingfish have a swimbladder until approximately 125 mm which may influence their feeding strategy (Ralph 1982).

Competition and Predation

No study has looked at competition and predation of juvenile northern kingfish but the juveniles likely compete with Gulf and southern kingfishes and members of the sciaenid family including spot, Atlantic croaker, weakfish, red drum, and black drum (Ralph 1982) as well as Florida pompano and silversides in the surfzone (Bearden 1963).

Part D. Adult Habitat

Adult northern kingfish are schooling fish that reside in both estuarine and nearshore Atlantic Ocean habitats. Adult northern kingfish are typically found over clean sandy sediment with some reports of northern kingfish found around hard substrate. Warming of coastal waters in the spring keys migration inshore and northward from the wintering grounds to nearshore-ocean, bays, estuaries and sounds. Northern kingfish migrate generally offshore and southward as temperatures decline in the fall.

Geographic and Temporal Patterns of Migration

Most northern kingfish mature after their first winter based (Schaefer 1965; Collier et al. in prep). The general pattern of adult habitat use is considered to be seasonal migrations south and offshore in fall and winter, and north and inshore during spring and summer (Irwin 1971; Ralph 1982; Miller et al. 2002). Summer inshore habitats are from the estuary to continental shelf in depths of less than 18 m (Ralph 1982). Although it is not clear the depth where overwintering occurs, northern kingfish have been captured in depths 36 m in the late fall off North Carolina with the deepest record being 128 m (Irwin 1971).

Salinity

Adult northern kingfish occur primarily in nearshore-ocean or lower estuarine habitats where salinities are near full seawater.

Substrate

In accordance with the variety of habitats used by adults, specific habitat use or habitat preference in adult northern kingfish has not been reported. Northern kingfish are typically found over sandy or muddy-sand substrates in the ocean, bays, and estuaries, but substrates used are likely as variable as the overall habitats in which adult northern kingfish are found. Some reports indicate that northern kingfish are found among hard substrate (Irwin 1971; Ralph 1982) and, anecdotally, fishermen indicated catches of northern kingfish are typically higher in close proximity to hard substrate.

Temperature

Temperature appears to be a driving factor in the movement of northern kingfish. Northern kingfish have reported temperature tolerances of 7.8 to 35.8° C. In areas south of Cape Hatteras, northern kingfish are rarely seen in temperatures less than 20° C. Northern kingfish have been reported dying due to cold stun has been reported in the northern part of their range (Irwin 1971). Northern kingfish have an upper thermal limit of 35° C and avoided temperatures greater than 31° C (Ralph 1982).

Dissolved Oxygen

Adult northern kingfish likely experience normoxic conditions, as they typically are found in lower estuary or nearshore-ocean. Without any explicit studies of adult northern kingfish dissolved oxygen tolerances or preferences, values might be inferred from other sciaenids that have overlapping habitat occurrences. It should be noted that the metabolic rate for northern kingfish was significantly higher than spot and Atlantic croaker (Horodysky et al. 2011).

Feeding Behavior

Adult northern kingfish are benthic feeders likely due to the lack of a swimbladder as an adult. The single barbel on the chin is used to detect the prey. Northern kingfish have been observed to have shrimp, amphipods, mysids, and polychaete worms (Welsh and Breder 1923; Woodland et al. 2011).

Competition and Predation

Competition among adult northern kingfish is not well known. Based on reports, northern kingfish overlap their distribution with southern and Gulf kingfishes; however the diet on Gulf kingfish appears to be much more specialized. The diets of southern and northern kingfish were examined in one study and were not found to form a single cluster indicating some niche segregation (Woodland et al. 2011). Other potential competitors include other members of the sciaenid family and Florida pompano. Kingfish spp. otoliths have been observed in the stomachs of cetaceans (Tyner 2004) and likely predators include larger sciaenids and coastal sharks.

<u>Section II. Essential Fish Habitats and Habitat Areas of Particular Concern</u>

Essential Fish Habitat

Identification of Habitat Areas of Particular Concern

There is no HAPC designation for northern kingfish.

Present Condition of Habitat Areas of Particular Concern

The quality of northern kingfish habitats has been compromised largely by impacts resulting from human activities. It is generally assumed that weakfish habitats have undergone some degree of loss and degradation; however, few studies that quantify impacts in terms of the area of habitat lost or degraded.

Loss due to water quality degradation is evident in the northeast Atlantic coast estuaries. The New York Bight is one example of an area that has regularly received deposits of contaminated dredged material, sewage sludge and industrial wastes. These deposits have contributed to oxygen depletion and the creation of large masses of anoxic waters during the summer months.

Some losses have likely occurred due to the intense coastal development that has occurred during the last several decades, although no quantification has been done. Losses have likely resulted from dredging and filling activities that have eliminated shallow water nursery habitat. Further functional losses have likely occurred due to water quality degradation resulting from point and non-point source discharges. Intensive conversion of coastal wetlands to agricultural use also is likely to have contributed to functional loss of northern kingfish nursery area habitat.

Other functional loss of riverine and estuarine areas may have resulted from changes in water discharge patterns resulting from withdrawals or flow regulation. Estuarine nursery areas for northern kingfish, as well as adult spawning and pre-spawning staging areas, may be affected by prolonged extreme conditions resulting from inland water management practices.

Beach renourishment projects are likely to have an impact on northern kingfish. Kingfish utilize the surfzone to different degrees as they progress through their life stages. Juveniles are localized-residents of the surfzone and lower estuaries (Miller et al. 2002). Northern kingfish were observed to increase in density during a beach renourishment project, potentially attracted to the bioturbation (Wilber et al. 2003). Short-term and long-term monitoring on the effects of beach renourishment is needed to better understand the impacts on kingfish.

Section II. Threats and Uncertainties

Significant Environmental, Temporal, and Spatial Factors Affecting Distribution of [Species]

Unknowns and Uncertainties

Little research has been conducted on northern kingfish at any life stage and a comprehensive coastwide study that covers their geographic range is needed. The impacts of dredge and fill projects including renourishment projects cannot be fully assessed without additional research to understand which habitats are essential fish habitat.

Section IV. Recommendations for Habitat Management and Research

Habitat Management Recommendations

- Protect known nursery areas from activities likely to negatively impact northern kingfish.
- Integrate beach and inlet management plans into a coastwide plan that minimizes impacts to the habitat of kingfishes and other estuarine fishes.
- Require beach renourishment and dredge and fill projects adhere to state, regional, or national policies.
- Modify stormwater rules or policies to more effectively reduce the volume and pollutant loading of stormwater runoff entering coastal waters.

Habitat Research Recommendations

- Conduct studies to delineate northern kingfish spawning habitat locations and environmental preferences (temperature, depth, substrate, etc) and enable quantification of spawning habitat.
- Compile existing data on larval and juvenile distribution from existing databases in order to obtain preliminary indications of spawning and nursery habitat location and extent.
- Define restrictions necessary for implementation of projects in spawning and overwintering areas and develop policies on limiting development projects seasonally or spatially.
- Recommend BACI studies for beach renourishment projects to describe the impact/benefit of renourishment.
- Develop consistent methods for studying impact of beach renourishment to allow for comparison spatially and temporally.
- Determine impact of beach stormwater outfalls on kingfish populations.
- Determine impact of bottom disturbing gear on kingfish spawning, nursery, and feeding habitats.

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CHAPTER 9: Southern Kingfish

Section I. General Description of Habitat

Southern kingfish are found in estuaries and coastal areas from Long Island, New York to Buenos Aires, Argentina (Irwin 1971) and are more common in the South Atlantic Bight than Mid-Atlantic Bight (Hildebrand and Schroeder, 1928; Smith and Wenner 1985). Southern kingfish prefer habitats in close proximity to inlets and in the ocean in depths ranging from 5 to 27 m (Bearden 1963; Harding and Chittenden 1987). Juvenile southern kingfish inhabit shallower waters than the adult southern kingfish and were typically found in waters less than 16 m and adults in waters less than 23 m (Bearden 1963; Crowe 1984; Harding and Chittenden 1987).

Part A. Spawning Habitat

Geographic and Temporal Patterns of Migration

Southern kingfish are thought to migrate southward during the winter and northward during prior to the spawning season (Hildebrand and Cable 1934; Smith and Wenner 1985). A tagging study of southern kingfish using T-bar and dart tags had few recaptures but the individuals tagged in the winter were recaptured near the tagging location as well as north and south of the tagging location (Beresoff and Schoolfield 1999). Fish tagged during the spawning season (April and May) were generally recaptured northward of the tagging location with some individuals recaptured in nearby inlets.

Salinity

Adult southern kingfish are thought to spawn in lower estuary and coastal habitats where the waters tend to have moderate to high salinities (Bearden 1963; Irwin 1971; Dalhberg 1972; Smith and Wenner 1985). Adult southern kingfish are found in higher salinity waters than juveniles and juveniles are rarely found in salinities less the 20 ppt (Bearden 1963; Irwin 1971; Crowe 1984).

Substrate

The spawning habitat has not been described for southern kingfish but southern kingfish are typically found over sandy and muddy (Welsh and Breder 1923; Hildebrand and Cable 1934; Bearden 1963). It is expected that southern kingfish spawn over sandy or muddy bottoms in the ocean and in deeper channels.

Temperature

Southern kingfish migrate based on temperature and will remain in the lower estuary and nearshore ocean during the spawning season. Southern kingfish have been observed in temperatures from 8 to 37° C (Crowe 1984). The temperature range is likely to vary with latitude with southern kingfish from Mid-Atlantic experiencing lower temperatures than fish inhabiting the South Atlantic and Gulf of Mexico. Temperature related fish kills have been reported during the winter which is out of the spawning time (Irwin 1971).

Dissolved Oxygen

Preferences for dissolved oxygen have not been reported for adult and spawning southern kingfish. Based on suspected spawning locations (deep estuaries and nearshore) low DO and hypoxic conditions are likely rare.

Feeding Behavior

Diets of southern kingfish were typically reported during the summer months which include the spawning season. The diet of southern kingfish typically comprised of fish (including silversides, anchovies, star drum, and tonguefish), Squilla, Crangon, Penaeid shrimp, mysids, polycheate worms, and copepods in the South Atlantic Bight (Irwin 1971; Woodland et al. 2011).

Competition and Predation

Competitors of southern kingfish likely include other members of sciaenid family including it congeners, southern and Gulf kingfishes, spot, Atlantic croaker, red drum, and black drum based on diet and habitat overlap. One study reported dietary overlap between southern kingfish, clearnose skate, and smooth dogfish (Woodland et al. 2011). Few studies have reported on competition or predation of spawning southern kingfish, though it might be safely inferred that adult competition and predation descriptions apply to spawners, particularly because the duration spawning season suggests that spawning is integrated into their adult lives, rather than a small, discrete period that may necessitate a different behavioral strategy.

Part B. Egg and Larval Habitat

The eggs of southern kingfish are buoyant and water column is the primary habitat. Eggs have been reported in the water column of the nearshore ocean and in estuaries.

Larvae of southern kingfish are defined as kingfish less than 25 mm standard length although the size of transition is not clearly defined (Welsh and Breder 1923). It is likely the nursery habitats for southern kingfish extend from the nearshore ocean into upper reaches of estuaries due to tidal transport. The greatest concentration of larvae southern kingfish occur in the nearshore ocean and lower estuaries (Irwin 1971; Ralph 1982; Flores et al. 1999; Reiss and McConaugha 1999; Markovsky 2009).

Geographic and Temporal Patterns of Migration

Mature southern kingfish spawn in the nearshore ocean and lower reaches of deep estuaries (NCDMF 2008). Spawning begins in the southern region of the distribution (e.g., Florida) early in the spring and likely begins later in the spring northern latitudes (Irwin 1971). Eggs are likely subjected to a variety of environmental conditions due to the protracted spawning season and broad geographic distribution from Florida to Maine in euryhaline areas similar to southern kingfish (Bearden 1963).

Southern kingfish larvae may be as distributed as any other life stage, as larvae have been reported in nearshore ocean waters and throughout estuaries (Bearden 1963; Irwin 1971; Crowe 1984). Larval southern kingfish migration has had little research. It is likely the larval transport of southern kingfish is similar to the larval transport of weakfish given the general overlap in spawning season and location. See Weakfish Geographic and Temporal Patterns of Migration for more information.

Salinity

Salinity has not been reported but eggs and larvae of kingfish (some studies do not differentiate) indicate they are concentrated in the ocean near inlets and the lower parts of estuaries where salinities are higher Flores et al. 1999; Reiss and McConaugha 1999; Markovsky 2009).

Southern kingfish larvae likely tolerate a wide range of salinities based on their wide distribution but are most common in waters with salinities greater than 20 ppt similar to southern kingfish (Bearden 1963). As southern kingfish grow, they are found in higher salinity waters (Bearden 1963; Crowe 1984). Although southern kingfish larvae are distributed over a range of salinities, it is not known if rapid changes in salinity impact survival.

Substrate

Commented [ML19]: Eggs copied from weakfish

Like many marine fish eggs, southern kingfish eggs are likely spherical, buoyant, and have a relatively short phase (compared to other life stages). The entire egg phase takes place in the pelagic zone of nearshore or lower estuarine waters, and thus substrate is not likely encountered.

Larval southern kingfish are likely planktonic and benthic (Hildebrand and Cable 1934). The likely substrates include sandy, muddy, and shell substrate in shallow estuarine and surfzone environments (Hildebrand and Cable 1934).

Temperature

Minimum temperature is likely the main driver of southern kingfish reproduction and thus a necessary condition for egg development. Based on observations for larval southern kingfish, southern kingfish were observed in temperatures from 24-30° C in the Gulf of Mexico (Crowe 1984). This range of temperatures might be narrower than the temperature tolerance in the Atlantic based on reported months of spawning from March to September (20-30° C).

Based on presence of southern kingfish recruiting at different times and different locations minimum temperature is likely important factor in their distribution. Based on average ocean temperatures for months listed when juvenile southern kingfish were captured, southern kingfish are found in temperatures between 20-30° C.

Dissolved Oxygen

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Dissolved oxygen is probably not an issue for short-lived southern kingfish eggs that remain buoyant and pelagic, and thus out of hypoxic and anoxic zones.

Due to a likely short larval duration similar to northern kingfish and the pelagic habitat, it is unlikely that they encounter any habitats in which dissolved oxygen imposes a limitation or threat.

Feeding Behavior

Unknown for southern kingfish eggs but likely subsist entirely off the yolk sac prior to hatch.

The feeding behaviors of larval southern kingfish has been described as more general than adults. The presence of a swimbladder as larvae and juvenile likely increases southern kingfish's ability to capture multiple prey sources (Welsh and Breder 1923). Additional research is needed, but the behaviors are likely similar to other sciaenids.

Competition and Predation

Southern kingfish eggs likely do not enter into any meaningful ecological competition, as their habitat demands are basic (and largely met by the offshore conditions). Predation of eggs undoubtedly occurs but has not been well studied or reported. Although potentially large numbers of eggs are killed from predation, there is no initial reason to think that pelagic oceanic predators are targeting weakfish eggs over other, similar pelagic eggs.

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No study has looked at competition and predation of larval southern kingfish but the larval like compete with Gulf and northern kingfishes and members of the sciaenid family including spot, Atlantic croaker, weakfish, red drum, and black drum (Ralph 1982) as well as Florida pompano and silversides in the surfzone (Bearden 1963). Some competition likely takes place when a high-density larval patch settles on limited habitat; however, the wide range of settled habitats and protracted spawning season suggest that widespread competition is unlikely.

Part C. Juvenile Habitat

Juvenile southern kingfish are generally between the sizes of 25 and 120-180 mm SL. The upper size varies between sexes due to the differential size at maturity. Juvenile southern kingfish inhabit the nearshore-ocean and surfzone and the deeper waters of bays, estuaries, and sounds, including their tributary rivers.

Geographic and Temporal Patterns of Migration

The general pattern of habitat use by juvenile southern kingfish is estuarine-wide but often most common beginning in late spring and early summer in lower estuarine and nearshore habitats and move to deeper more saline waters in the fall (Crowe 1984). Southern kingfish are summer residents of the surfzone and estuaries (Dalhberg 1972; Crowe 1984).

Salinity

Juvenile southern kingfish migrate to deeper more saline waters as they get larger. By the fall most southern kingfishes migrate out of the shallow estuarine and nearshore ocean environment to the deeper ocean habitats to overwinter (Bearden 1963; Harding and Chittenden 1987). The fish tended to leave the estuarine beaches at smaller sizes than at oceanic beaches (160 mm TL vs 200 TL) (Harding and Chittenden 1987). It is not known if salinities impact growth rates.

Substrate

Juvenile southern kingfish are typically observed over sandy, muddy, and shell substrate in shallow estuarine and surfzone environments (Bearden 1963; Irwin 1971; Harding and Chittenden 1987). In the fall, the most juvenile southern kingfish will migrate into the ocean (Hildebrand and Cable 1934; Smith and Wenner 1985; Harding and Chittenden 1987). However some individuals will remain in the estuary throughout the winter (Bearden 1963).

Temperature

Juvenile southern kingfish likely tolerate a wide range of temperatures, though temperature is considered to be an important variable driving their distribution. Juvenile southern kingfish are rarely seen in temperatures below 15° C and migrate out of shallow waters in September and October (Crowe 1984; Harding and Chittenden 1987).

Dissolved Oxygen

Little has been reported on the impact of dissolved oxygen levels on juvenile southern kingfish. The lower estuary and surfzone environments may have fewer occurrences of hypoxic and anoxic events compared to upper estuarine habitats. However, southern kingfish do have a relatively fast growth rate (Hildebrand and Cable 1934; Bearden 1963; Crowe 1984) and likely contributes to the elevated metabolic rate (Horodysky et al. 2011).

Feeding Behavior

Juvenile southern kingfish are typically described as benthic foragers. They use their barbel to detect prey. The juvenile diet consists of nematodes, polychaete worms, mysid shrimp, penaeid shrimp, isopods, amphipods copepods, fishes, and detritus (Welsh and Breder 1923; Bearden 1963). Juvenile southern kingfish have a swimbladder until approximately 125 mm which may influence their feeding strategy (Bearden 1963).

Competition and Predation

No study has looked at competition and predation of juvenile southern kingfish but the juveniles like compete with Gulf and northern kingfishes and members of the sciaenid family including spot, Atlantic croaker, weakfish, red drum, and black drum (Ralph 1982) as well as Florida pompano and silversides in the surfzone (Bearden 1963).

Part D. Adult Habitat

Adult southern kingfish are schooling fish that reside in both estuarine and nearshore Atlantic Ocean habitats. Adult southern kingfish are typically found over clean sandy sediment with some reports of southern kingfish found over muddy and shell bottoms. Warming of coastal waters in the spring keys migration northward from the wintering grounds (Smith and Wenner 1985). Southern kingfish migrate generally southward as temperatures decline in the fall (Smith and Wenner 1985). Limited tagging of adult kingfish indicates a northward and inshore migration as waters warm (Beresoff and Schoolfield 2002).

Geographic and Temporal Patterns of Migration

Most southern kingfish mature after their first winter based (Smith and Wenner 1985; Collier et al. in prep). The general pattern of adult habitat use is considered to be seasonal migrations south and offshore in fall and winter, and north and inshore during spring and summer (Irwin 1971; Smith and Wenner 1985). Summer inshore habitats are from the estuary to continental shelf in depths of less than 5 to 30 m (Harding and Chittenden 1987). Although it is not clear the depth where overwintering occurs, southern kingfish have been captured in depths up to 54 m in the late fall (Bearden 1963).

Salinity

Adult southern kingfish occur primarily in nearshore-ocean or lower estuarine habitats where salinities are near full seawater.

Substrate

In accordance with the variety of habitats used by adults, specific habitat use or habitat preference in adult southern kingfish has not been reported. Southern kingfish are typically found over sandy or muddy-sand substrates in the ocean, bays, and estuaries, but substrates used are likely as variable as the overall habitats in which adult southern kingfish are found (Irwin 1971; Harding and Chittenden 1987).

Temperature

Temperature appears to be a driving factor in the movement of southern kingfish. Southern kingfish have reported temperature tolerances of 7 to 33° C (Irwin 1971; Crowe 1984). In areas south of Cape Hatteras, southern kingfish are more commonly seen in temperatures greater than 15° C (Irwin 1971).

Dissolved Oxygen

Adult southern kingfish likely experience normoxic conditions, as they typically are found in lower estuary or nearshore-ocean. Without any explicit studies of adult southern kingfish dissolved oxygen tolerances or preferences, DO requirements might be inferred from other sciaenids with overlapping habitat occurrences. It should be noted that the metabolic rate for southern kingfish was significantly higher than spot and Atlantic croaker (Horodysky et al. 2011).

Feeding Behavior

Adult southern kingfish are benthic feeders likely due to the lack of a swimbladder as an adult. The single barbel on the chin is used to detect the prey. The diet of southern kingfish typically comprised of fish (including silversides, anchovies, star drum, and tonguefish), Squilla, Crangon, Penaeid shrimp, mysids, polycheate worms, and copepods in the South Atlantic Bight (Irwin 1971; Woodland et al. 2011).

Competition and Predation

Competition among adult southern kingfish is not well known. Based on reports, southern kingfish overlap their distribution with northern and Gulf kingfishes; however the diet of Gulf kingfish appears to be much more specialized. The diet of southern and northern kingfishes were examined in one study and were not found to form a single cluster indicating some niche segregation; however, southern kingfish diets did overlap with smooth dogfish and clearnose skates (Woodland et al. 2011). Other potential competitors include other members of the sciaenid family and Florida pomapano.

Kingfish spp. otoliths have been observed in the stomachs of cetaceans (Tyner 2004) and likely predators include larger sciaenids and coastal sharks.

Section II. Essential Fish Habitats and Habitat Areas of Particular Concern

Essential Fish Habitat

Identification of Habitat Areas of Particular Concern

There is no HAPC designation for southern kingfish.

Present Condition of Habitat Areas of Particular Concern

The quality of southern kingfish habitats has been compromised largely by impacts resulting from human activities. It is generally assumed that weakfish habitats have undergone some degree of loss and degradation; however, few studies that quantify impacts in terms of the area of habitat lost or degraded.

Loss due to water quality degradation is evident in the northeast Atlantic coast estuaries. The New York Bight is one example of an area that has regularly received deposits of contaminated dredged material, sewage sludge and industrial wastes. These deposits have contributed to oxygen depletion and the creation of large masses of anoxic waters during the summer months.

Some losses have likely occurred due to the intense coastal development that has occurred during the last several decades, although no quantification has been done. Losses have likely resulted from dredging and filling activities that have eliminated shallow water nursery habitat. Further functional losses have likely occurred due to water quality degradation resulting from point and non-point source discharges. Intensive conversion of coastal wetlands to agricultural use also is likely to have contributed to functional loss of southern kingfish nursery area habitat.

Other functional loss of riverine and estuarine areas may have resulted from changes in water discharge patterns resulting from withdrawals or flow regulation. Estuarine nursery areas for southern kingfish, as well as adult spawning and pre-spawning staging areas, may be affected by prolonged extreme conditions resulting from inland water management practices.

Beach renourishment projects are likely to have an impact on southern kingfish. Kingfish utilize the surfzone to different degrees as they progress through their life stages. Juveniles are localized-residents of the surfzone and lower estuaries (Miller et al. 2002). Southern kingfish were observed to increase in density during a beach renourishment project, potentially attracted to the bioturbation (Wilber et al. 2003). Short-term and long-term monitoring on the effects of beach renourishment is needed to better understand the impacts on kingfish.

Section II. Threats and Uncertainties

Significant Environmental, Temporal, and Spatial Factors Affecting Distribution of [Species]

Unknowns and Uncertainties

Little research has been conducted on southern kingfish at any life stage and a comprehensive coastwide study that covers their geographic range is needed. The impacts of dredge and fill projects including renourishment projects cannot be fully assessed without additional research to understand which habitats are essential fish habitat.

Section IV. Recommendations for Habitat Management and Research

Habitat Management Recommendations

- Protect known nursery areas from activities likely to negatively impact southern kingfish.
- Integrate beach and inlet management plans into a coastwide plan that minimizes impacts to the habitat of kingfishes and other estuarine fishes.
- Require beach renourishment and dredge and fill projects adhere to state, regional, or national policies.
- Modify stormwater rules or policies to more effectively reduce the volume and pollutant loading of stormwater runoff entering coastal waters.

Habitat Research Recommendations

- Conduct studies to delineate southern kingfish spawning habitat locations and environmental preferences (temperature, depth, substrate, etc.) and enable quantification of spawning habitat.
- Compile existing data on larval and juvenile distribution from existing databases in order to obtain preliminary indications of spawning and nursery habitat location and extent.
- Define restrictions necessary for implementation of projects in spawning and overwintering areas and develop policies on limiting development projects seasonally or spatially.
- Recommend BACI studies for beach renourishment projects to describe the impact/benefit of renourishment.
- Develop consistent methods for studying impact of beach renourishment to allow for comparison spatially and temporally.
- Determine impact of beach stormwater outfalls on kingfish populations.
- Determine impact of bottom disturbing gear on kingfish spawning, nursery, and feeding habitats.

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CHAPTER 10: Gulf Kingfish

Section I. General Description of Habitat

Gulf kingfish are found in coastal areas from Chincoteague, Virginia to Rio Grande, Brazil and is most common south of Cape Hatteras and in the Gulf of Mexico (Irwin 1971). Gulf kingfish prefer surfzone habitats and in the ocean in depths less than 10 meters (Welsh and Breder 1923; Bearden 1963; Irwin 1971). Gulf kingfish are rarely found in habitats other than the nearshore-ocean unlike southern and northern kingfishes which utilize estuarine habitats along with the nearshore-ocean.

Part A. Spawning Habitat

Geographic and Temporal Patterns of Migration

Gulf kingfish are thought to migrate inshore and northward from their overwintering habitats during the spring and summer while spawning is occurring (Hildebrand and Cable 1934). Fish in spawning condition have been observed from April through September based on macroscopic inspection of gonads for fish in North Carolina (Collier in prep) and from April through September based on the size distribution of young of the year fish (Hildebrand and Cable 1934; Bearden 1963; Modde 1980). Spawning is suggested to occur in the nearshore ocean (Irwin 1971) and migrate to shallower water for spawning (Braun and Fontoura 2004).

Salinity

Adult gulf kingfish spawn in the nearshore-ocean where the waters are at full salinity (Braun and Fontoura 2004).

Substrate

The spawning habitat has not been described for gulf kingfish but gulf kingfish are typically found over sandy bottoms (Hildebrand and Cable 1934; Bearden 1963).

Temperature

Gulf kingfish migrate based on temperature and nearshore ocean during the spawning season. Gulf kingfish have been observed in temperatures from 10 to 31° C (Irwin 1971). Little research has been conducted on temperature preferences for spawning gulf kingfish but based on the temperatures when YOY Gulf kingfish are observed spawning likely occurs between 18 and 30° C.

Dissolved Oxygen

Preferences for dissolved oxygen have not been reported for adult and spawning gulf kingfish. Based on suspected spawning locations (and nearshore) low DO and hypoxic conditions are likely rare.

Feeding Behavior

Diets of gulf kingfish were typically reported during the summer months which includes the spawning season. The diet of gulf kingfish are more specialized than northern and southern kingfishes likely due to their more limited habitat range and molar-like pharnygeal teeth. Gulf kingfish diet includes mole crabs, Donax, polychaetes, brachyurans, stomatopod, Squilla, and fishes (Bearden 1963; McMichael and Ross 1987).

Competition and Predation

Competitors of gulf kingfish likely include other members of sciaenid family including it congeners, southern and gulf kingfishes, spot, Atlantic croaker, red drum, and black drum based on diet and habitat overlap. No studies have reported on competition or predation of spawning gulf kingfish, though it might be safely inferred that adult competition and predation descriptions apply to spawners, particularly because the duration spawning season suggests that spawning is integrated into their adult lives, rather than a small, discrete period that may necessitate a different behavioral strategy.

Part B. Egg and Larval Habitat

The eggs of gulf kingfish are likely buoyant and water column is the primary habitat. Research has not been conducted on egg and larval development of gulf kingfish.

Larvae of gulf kingfish are defined as kingfish less than 25 mm standard length although the size of transition is not clearly defined (Hildebrand and Cable 1934). It is likely the nursery habitats for gulf kingfish extend from the nearshore-ocean to the surfzone. The greatest concentration of larvae gulf kingfish occur in the nearshore-ocean and surfzone (Bearden 1963; Irwin 1971; Modde 1980).

Geographic and Temporal Patterns of Migration

Mature gulf kingfish spawn in the nearshore ocean (Braun and Fontoura 2004). Eggs are likely subjected to a variety of environmental conditions due to the protracted spawning season and broad geographic distribution from Florida to Virginia but typically are found in euhaline waters (Bearden 1963).

Gulf kingfish larvae may be as distributed as any other life stage, as larvae have been reported in nearshore-ocean waters and surfzone (Bearden 1963; Irwin 1971). Larval gulf kingfish migration has had little research. It is likely the larval transport of gulf kingfish is through longshore currents; however few larvae are outside of the surfzone

Salinity

Salinity preferences/tolerances have not been reported for gulf kingfish eggs but larvae and juveniles of gulf kingfish are rarely reported in areas other than nearshore-ocean and surfzone. It is not known if eggs can tolerate salinities less than full strength seawater, but larvae and juvenile Gulf kingfish are rare in estuaries.

Gulf kingfish larvae likely tolerate a narrow range of salinities based on their primarily oceanic distribution (Bearden 1963).

Substrate

Like many marine fish eggs, gulf kingfish eggs are likely spherical, buoyant, and have a relatively short phase (compared to other life stages). The entire egg phase takes place in the pelagic zone of nearshore or lower estuarine waters, and thus substrate is not likely encountered.

It is not known if larval gulf kingfish are planktonic because the swimbladder of gulf kingfish is atrophied at a smaller size than northern and southern kingfishes. If the larvae a planktonic, the larvae would not come in contact with the large variety of substrate types over which they are dispersed. However if they do settle, they likely settle on sand substrate similar to the substrate juveniles are found over.

Temperature

Minimum temperature is likely the main driver of gulf kingfish reproduction and thus a necessary condition for egg development. Gulf kingfish are uncommon under 20 C (Bearden 1963) in the nearshore ocean which is the spawning location (Braun and Fontoura 2004). Based on average ocean temperatures for months listed as spawning times, gulf kingfish likely spawn at temperatures between 18-27° C.

Based on presence of gulf kingfish recruiting at different times and different locations minimum temperature is likely important factor in their distribution. Based on average ocean temperatures for months listed when juvenile gulf kingfish were captured, gulf kingfish are found in temperatures between 18-27° C.

Dissolved Oxygen

Dissolved oxygen is probably not an issue for short-lived gulf kingfish eggs that likely remain buoyant and pelagic, and thus out of hypoxic and anoxic zones.

Due to the likely short larval duration and oceanic habitat, it is unlikely that they encounter any habitats in which dissolved oxygen imposes a limitation or threat.

Feeding Behavior

Gulf kingfish eggs likely subsist entirely off the yolk sac prior to hatch.

The feeding behaviors of larval gulf kingfish have not been described. Additional research is needed, but the behaviors are likely similar to other sciaenids.

Competition and Predation

Gulf kingfish eggs likely do not enter into any meaningful ecological competition, as their habitat demands are basic (and largely met by the offshore conditions). Predation of eggs undoubtedly occurs but has not been well studied or reported. Although potentially large numbers of eggs are killed from predation, there is no initial reason to think that pelagic oceanic predators are targeting weakfish eggs over other, similar pelagic eggs.

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No study has looked at competition and predation of larval gulf kingfish but the larval like compete with northern and southern kingfishes (McMichael and Ross 1987) and members of the sciaenid family including spot, Atlantic croaker, weakfish, red drum, and black drum (Ralph 1982) as well as Florida pompano and silversides in the surfzone (Bearden 1963). Some competition likely takes place when a high-density larval patch settles on limited habitat; however, the wide range of settled habitats and protracted spawning season suggest that widespread competition is unlikely.

Part C. Juvenile Habitat

Juvenile gulf kingfish are kingfish general between the sizes of 25 and 150-230 mm SL. The upper size varies between sexes due to the differential size at maturity. Juvenile gulf kingfish inhabit the nearshore-ocean and surfzone. gulf kingfish were found to be summer residents of the surfzone (Ross and Lancaster 2002; Felix et al. 2007; Branson 2009).

Geographic and Temporal Patterns of Migration

The general pattern of habitat use by juvenile gulf kingfish is typically described as the surfzone beginning in late spring and early summer in lower estuarine and nearshore habitats and move to deeper waters as temperatures cool (Braun and Fontoura 2004). Gulf kingfish tend to remain in localized areas throughout the summer (Ross and Lancaster 2002; Felix et al. 2007; Branson 2009).

Salinity

Juvenile gulf kingfish migrate to deeper waters as they get larger (Braun and Fontoura 2004). By the fall most gulf kingfishes migrate out of the nearshore ocean environment to the deeper ocean habitats to overwinter (Bearden 1963).

Substrate

Juvenile gulf kingfish are typically observed over sandy sediment in surfzone environments (Hildebrand and Cable 1934; Irwin 1971; Ross and Lancaster 2002). There are few reports of gulf kingfish being caught in estuaries (Bearden 1963; Irwin 1971; Branson 2009).

Temperature

Juvenile gulf kingfish likely tolerate a wide range of temperatures, though temperature is considered to be an important variable driving their distribution. Juvenile gulf kingfish are rarely seen in temperatures below 20° C and migrate out of shallow waters in September and October (Bearden 1963; Modde 1980).

Dissolved Oxygen

Little has been reported on the impact of dissolved oxygen levels on juvenile gulf kingfish. The surfzone environment may have fewer occurrences of hypoxic and anoxic events compared to estuarine habitats.

Feeding Behavior

Juvenile gulf kingfish are typically described as benthic foragers. They use their barbel to detect prey and their molar-like pharyngeal teeth to crush shells. The juvenile diet consists of Donax siphon tips, cumaceans, mysids, Orchestia (Bearden 1963; McMichael and Ross 1987). Juvenile gulf kingfish appear to atrophy their swimbladder at smaller size than other kingfishes and likely switch to a more benthic diet at a smaller size.

Competition and Predation

No study has looked at competition and predation of juvenile gulf kingfish but the juveniles like compete with northern and southern kingfishes (McMichael and Ross 1987) and members of the sciaenid family including spot, Atlantic croaker, weakfish, red drum, and black drum (Ralph 1982) as well as Florida pompano and silversides in the surfzone (Bearden 1963).

Part D. Adult Habitat

Adult gulf kingfish reside in nearshore Atlantic Ocean habitats. Adult gulf kingfish are typically found over clean sandy sediment with some reports of gulf kingfish found in estuarine habitats. Most gulf kingfish mature after their first winter based on macroscopic observations (Collier et al. in prep). Warming of coastal waters in the spring keys migration inshore and northward from the wintering grounds. Gulf kingfish migrate generally offshore and southward as temperatures decline in the fall.

Geographic and Temporal Patterns of Migration

The general pattern of adult habitat use is considered to be seasonal migrations south and offshore in fall and winter, and north and inshore during spring and summer (Irwin 1971). Although it is not clear the depth where overwintering occurs, gulf kingfish have been captured in depths 27 m in the Gulf of Mexico during the winter (Irwin 1971). Adult gulf kingfish migrate inshore from deeper habitats during spawning (Braun and Fontoura 2004).

Salinity

Adult gulf kingfish occur primarily in nearshore-ocean habitats where salinities are near full seawater.

Substrate

Gulf kingfish are typically found over sandy substrates in the nearshore-ocean and surfzone. Some reports indicate that gulf kingfish are rarely found in estuaries (Irwin 1971).

Temperature

Temperature appears to be a driving factor in the movement of gulf kingfish. Gulf kingfish have reported temperature tolerances of 10 to 31° C (Irwin 1971). Gulf kingfish are rarely seen in temperatures less than 20° C (Bearden 1963).

Dissolved Oxygen

Adult gulf kingfish likely experience normoxic conditions, as they typically are found in the nearshore-ocean. Without any explicit studies of adult gulf kingfish dissolved oxygen tolerances or preferences, values might be inferred from other sciaenids that have overlapping habitat occurrences. It should be noted that the metabolic rate for other kingfishes was significantly higher than spot and Atlantic croaker (Horodysky et al. 2011).

Feeding Behavior

Adult gulf kingfish are benthic feeders likely due to the lack of a swimbladder as an adult. The single barbel on the chin is used to detect the prey and the molar-like pharyngeal teeth are used to crush shell.

Competition and Predation

Competition among adult gulf kingfish is not well known. Based on reports, gulf kingfish overlap their distribution with southern and northern kingfishes (McMichael and Ross 1987); however the diet of gulf kingfish appears to be much more specialized. The diet of gulf kingfish has been reported to include: whole Donax, polychaetes, Emerita, brachyurans, Squilla, and fishes (Bearden 1963; McMichael and Ross 1987). Other potential competitors include other members of the sciaenid family and Florida pomapano.

Kingfish spp. otoliths have been observed in the stomachs of cetaceans (Tyner 2004) and likely predators include larger sciaenids and coastal sharks.

Section II. Essential Fish Habitats and Habitat Areas of Particular Concern

Essential Fish Habitat

Identification of Habitat Areas of Particular Concern

There is no HAPC designation for gulf kingfish.

Present Condition of Habitat Areas of Particular Concern

The quality of gulf kingfish habitats has been compromised largely by impacts resulting from human activities. It is generally assumed that weakfish habitats have undergone some degree of loss and degradation; however, few studies that quantify impacts in terms of the area of habitat lost or degraded.

Some losses have likely occurred due to the intense coastal development that has occurred during the last several decades, although no quantification has been done. Losses have likely resulted from dredging and filling activities that have eliminated shallow water nursery habitat. Further functional losses have likely occurred due to water quality degradation resulting from point and non-point source discharges.

Beach renourishment projects is likely to have an impact on gulf kingfish. Kingfish utilize the surfzone to different degrees as they progress through their life stages. Juveniles are localized-residents of the surfzone (Ross and Lancaster 2002; Felix et al. 2007) and are found in few other habitats. Short-term and long-term monitoring on the effects of beach renourishment is needed to better understand the impacts on kingfish.

Section II. Threats and Uncertainties

Significant Environmental, Temporal, and Spatial Factors Affecting Distribution of [Species]

Unknowns and Uncertainties

Little research has been conducted on gulf kingfish at any life stage and a comprehensive coastwide study that covers their geographic range is needed. The impacts of dredge and fill projects including renourishment projects cannot be fully assessed without additional research to understand which habitats are essential fish habitat.

Section IV. Recommendations for Habitat Management and Research

Habitat Management Recommendations

- Protect known nursery areas from activities likely to negatively impact gulf kingfish.
- Integrate beach and inlet management plans into a coastwide plan that minimizes impacts to the habitat of kingfishes and other estuarine fishes.
- Require beach renourishment and dredge and fill projects adhere to state, regional, or national policies.
- Modify stormwater rules or policies to more effectively reduce the volume and pollutant loading of stormwater runoff entering coastal waters.

Habitat Research Recommendations

- Conduct studies to delineate gulf kingfish spawning habitat locations and environmental preferences (temperature, depth, substrate, etc) and enable quantification of spawning habitat.
- Compile existing data on larval and juvenile distribution from existing databases in order to obtain preliminary indications of spawning and nursery habitat location and extent.
- Define restrictions necessary for implementation of projects in spawning and overwintering areas and develop policies on limiting development projects seasonally or spatially.
- Recommend BACI studies for beach renourishment projects to describe the impact/benefit of renourishment.
- Develop consistent methods for studying impact of beach renourishment to allow for comparison spatially and temporally.
- Determine impact of beach stormwater outfalls on kingfish populations.
- Determine impact of bottom disturbing gear on kingfish spawning, nursery, and feeding habitats.

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Gulf Kingfish

Chapter 11: Habitat-Related Threats to Atlantic Sciaenids

Section I. Identification of Threats

Threat 1
Source of Threat
Rank of Threat (ex. Low, Medium, High)

Threat 2
Source of Threat
Rank of Threat

Threat 3
Source of Threat
Rank of Threat
…

Section II. Effects of Habitat Degradation on Sciaenid Populations

Section III. Recommendations to Mitigate Threats to Sciaenid Habitats

Literature Cited

Gulf Kingfish

Chapter 12: Future Habitat Research Information Needs for Sciaenid Species

Section I: General Research Needs for Atlantic Sciaenids

Section II: Species-Specific Research Needs

Goal 4 – Protect and enhance fish habitat and ecosystem health through partnerships and education

Goal 4 aims to conserve and improve coastal, marine, and riverine habitat to enhance the benefits of sustainable Atlantic coastal fisheries and resilient coastal communities in the face of changing ecosystems. Habitat loss and degradation have been identified as significant factors affecting the long-term sustainability and productivity of our nation's fisheries. The Commission's Habitat Program develops objectives, sets priorities, and produces tools to guide fisheries habitat conservation efforts directed towards ecosystem-based management.

The challenge for the Commission and its state members is maintaining fish habitat in the absence of specific regulatory authority for habitat protection or enhancement. Therefore, the Commission will work cooperatively with state, federal, and stakeholder partnerships to achieve this goal. The Commission and its Habitat Program endorses the National Fish Habitat Partnership, and will continue to work cooperatively with the program to improve aquatic habitat along the Atlantic coast. Since 2008, the Commission has invested considerable resources, as both a partner and administrative home, to the Atlantic Coastal Fish Habitat Partnership (ACFHP), a coastwide collaborative effort to accelerate the conservation and restoration of habitat for native Atlantic coastal, estuarine-dependent, and diadromous fishes.

Strategies to Achieve Goal

4.1 Review habitat program goals and evaluate accomplishments annually.

4.2 Identify critical habitat through fisheries management programs and partnerships.

Task 4.2.1 – Finalize the sciaenid habitat source document working closely with technical committees, other species experts, and staff.

Task 4.2.2 – Prioritize and publicize important habitat types for Commission-managed species as identified in the ACFHP Strategic Plan and Habitat Committee Guidance Document.

Task 4.2.3 – Update species habitat factsheets for publishing in late 2016.

Task 4.2.4 – Coordinate artificial reef activities among the Atlantic coast states, and between the Atlantic and Gulf States Marine Fisheries Commissions.

4.3 Educate Commissioners, stakeholders, and the general public about the importance of habitat to healthy fisheries and ecosystems.

Task 4.3.1 – Facilitate coordination and distribution of information for ecosystem-based management and marine protected area activities, and the potential consequences of significant anthropogenic activities on habitats of concern.

Task 4.3.2 – Participate in regional and national habitat meetings and scientific conferences to facilitate increased communication with agencies and programs that have jurisdiction over habitat.

Task 4.3.3 – Publish annual issue of *Habitat Hotline Atlantic*.

Task 4.3.4 – Finalize installment of the Habitat Management Series: *Aquaculture* for ISFMP Policy Board review and acceptance. Identify a subsequent topic (e.g. *Climate Change, Sand Mining, Power Plant Impingement*).

4.4 Engage local, state and regional governments in mutually beneficial habitat protection and enhancement programs through partnerships.

Task 4.4.1 – Work with ACFHP to foster partnerships with like-minded organizations at local levels to further common habitat goals.

Task 4.4.2 – Provide stakeholders with the tools to effectively communicate, promote and accomplish habitat protection, restoration, and enhancement programs at the local level.

Task 4.4.3 – Serve as a point of contact and information conduit at the Commission for energy-related issues affecting fish habitat.

Task 4.4.4 – Continue to provide coordination support for ACFHP, under the direction of the National Fish Habitat Action Plan (NFHAP) Board.

Subtask 4.4.4.1 – Facilitate communication and outreach with ACFHP partners, overlapping partnerships, and new partners. Develop outreach materials and maintain the ACFHP website.

Subtask 4.4.4.2 – Continue the implementation of the 5-year ACFHP Conservation Strategic Plan by reviewing, determining the status of, and accomplishing the tasks outlined in the Implementation Plan.

Subtask 4.4.4.3 – Progress on ACFHP Science and Data projects – finalize the winter flounder and river herring habitat assessment, make results available to Partners for the purpose of strategic coastal habitat conservation; solicit and select projects that research artificial and natural reefs off the Mid-Atlantic Coast.

Subtask 4.4.4.4 – Work with state and federal agencies, the Councils, and non-governmental organizations to build on existing efforts to populate coast wide GIS databases of fish habitat resources, to identify important fish habitats for Commission managed species as defined in the ACFHP Species-Habitat matrix.

Subtask 4.4.4.5 – Work with the U.S. Fish and Wildlife Service and National Fish Habitat Partnership to fund on the ground fish habitat restoration projects within ACFHP boundaries.

4.5 Foster partnerships with management agencies, researchers, and habitat stakeholders to leverage regulatory, political, and financial support.

Task 4.5.1 – Provide information or comment on Atlantic coast projects and permits in accordance with ASMFC project review protocol.

Task 4.5.2 – Facilitate funding and partnership opportunities to promote habitat research in the states.

Task 4.5.3 – Identify partnership opportunities and forge additional relationships with organizations – such as non-governmental organizations and the recreational fishing community – to facilitate the promotion of fish habitat through a collaboration of strengths of different stakeholder groups.

Task 4.5.4 –Use social media to connect with regional and local decision makers.

4.6 Engage in state and federal agency efforts to ensure climate change response strategies and ecosystem based management are included in habitat conservation efforts.

Task 4.6.1 – As revisions to habitat sections of FMPs are made, include recommendations to mitigate climate change impacts on habitat.

Task 4.6.2 – Identify inconsistencies in state coastal regulatory planning programs and develop recommendations for improvements to the ISFMP Board.

Task 4.6.3 – Increase communication on ecosystem based management with ASMFC committees to find overlap with fish habitat-related issues.

Habitat Management Series: Estuarine and Nearshore Aquaculture

The Habitat Management Series (HMS) installment on estuarine and nearshore aquaculture is envisioned to be an objective review of aquaculture practices and effects, from good to bad, on fish habitats. It will not be an expansive review of aquaculture as was the ASMFC's *Guidance to Development of Responsible Aquaculture Activities in Atlantic Coast States* (SR76), which is dated. Rather, the HMS aquaculture issue will be a narrowly focused exploration of how fish habitat responds to aquaculture activity located in the same vicinity. The narrative will have a similar structure as previous HMS issues; except throughout the document will be case-study narratives formatted as sidebars that relate to the issues being covered. Topics will be reviewed in a coast-wide context since there are a variety of genera that are cultured using a number of different techniques located from coastal waters inland to artificial coastal ponds. The HMS document will not explore policy issues, human health, industry development, or other such topics.

Progress	Section	Fearless Author
	Introduction	Marek
	Current Policies	
	Range of Species most common to nearshore aquaculture	
	Types of facilities	
	Various purposes of nearshore aquaculture operations	
	Side Bar: water quality impacts	
	Side Bar: structural modification	
	Side Bar: biological community modification	
	Resources	

I. Introduction – Discuss possibly focusing more on the most prevalent type of aquaculture that managers deal with. Describe topics that are covered, as well as those that are not.

II. Current policy (succinct summaries)
    a. U. S. Department of Commerce Aquaculture Policy
    b. ASMFC (review section from SR76's Intro and update)
    c. NEFMC, MAFMC, and SAFMC policy statements

III. Varieties of coastal/estuarine aquaculture and their impacts (positive and negative) on habitats. Address the good, bad, and uncertainties based on program experiences and/or peer-reviewed literature. For each component, focus on the ones most important to estuarine/nearshore aquaculture and briefly describe the rest.
    a. Range of species -
        i. Finfish
        ii. Shellfish – with oyster, clams, scallops, mussels as dominant

        - iii. Kelp/macroalgae
        - iv. Invertebrates: shrimp, etc.
    - b. Types of facilities
        - i. Floating
        - ii. Benthic
        - iii. coastal pond
        - iv. Net pen
        - v. Hatcheries, land-based raceways and seed nursery systems
    - c. Various purposes
        - i. Industrial
        - ii. Boutique
        - iii. Research
        - iv. Spatial Planning and interaction with industry and stakeholders
        - v. Other?

- IV. Case studies/Side bars to explore impacts to fish habitat. Keep this section brief. Perhaps select 2-3 examples of each category below.
    - a. Water quality impacts
        - i. Water filtration (nutrient and Chlorophyll a)
        - ii. Nutrient accumulation (feces build up)
        - iii. Modification of benthic biogeochemistry shells buffering estuarine acidification
        - iv. Accidental discharges
        - v. Other ?
    - b. Structural modification
        - i. SAV shading
        - ii. Addition of hard structure
        - iii. Loss of inert sediment habitat (scale context is necessary here – conversion of mud flat or barren bottom to oyster reef or oyster racks is probably more additive to habitat than maintaining that in current state)
        - iv. Pelagic shelter/habitat
        - v. Loss of wetlands/mangrove (estuarine shoreline habitats)
        - vi. Hydrodynamic and flow changes
        - vii. Other ? living shorelines??? As part of habitat / aquaculture initiatives?
    - c. Biological community modification (invasives and disease)
    - d. Other ??

- V. Resources
    - a. Agency contacts
    - b. Peer-reviewed literature: highlight credible science on controversial issues.
    - c. Links to state and federal agency websites/contacts
        - i. NMFS http://www.nmfs.noaa.gov/aquaculture/aquaculture_in_us.html

ii. Interstate Shellfish Sanitation Conference which guides state programs on shellfish production through model ordinance http://www.issc.org/Default.aspx
iii. USFDA http://www.fda.gov/animalveterinary/developmentapprovalprocess/aquaculture/default.htm
iv. USDA (most recent survey updated 2005) http://www.usda.gov/wps/portal/usda/usdahome?navid=AQUACULTURE&parentnav=PRODUCERS&navtype=RT_

Restoration of Dragline Ditched Coastal Wetlands:

Cooperative Efforts for the Future of Our Coastal Systems

History of Dragline Ditching for Mosquito Control

What: Dragline ditches are extensive networks of deep, wide ditches and spoil piles cut through historical coastal wetland habitat severely reducing the acreage of wetland remaining.

When: Primarily in 1950s and 1960s

Where: The most extensive ditching occurred in Mosquito Lagoon (nearly 1,200 acres), though some ditching is present throughout Indian River Lagoon and the Northern Coastal Basins.

Why: The purpose of the ditches was to interrupt the life cycle of saltmarsh mosquitoes by altering their breeding sites. The ditching replaced wetland with ditch and spoil piles decreasing the area where mosquitoes lay eggs, altering the hydrology of the remaining wetland, and provide direct access for mosquito-eating fishes.

Figure 1.

How: Large excavators, called draglines, were used to construct these ditch networks. The draglines were typically mounted to small barges (see Figure 1). Material was excavated from the wetlands and piled on either side of the ditch (see Figure 2).

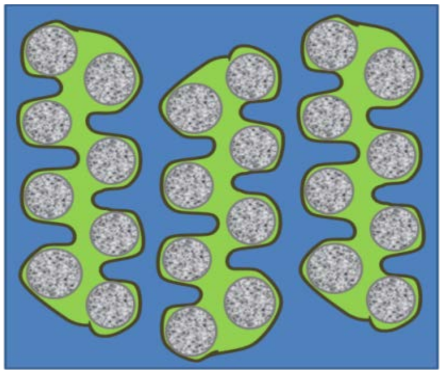
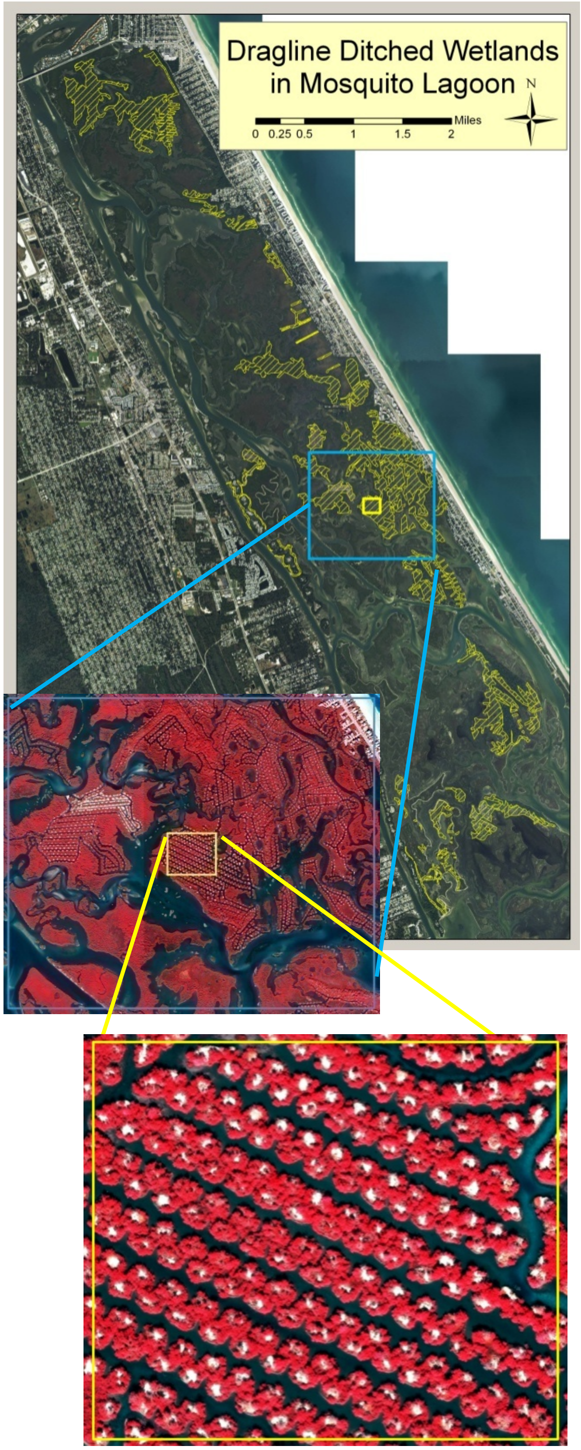


Figure 2.



Negative Impacts of Dragline Ditches

Decreased Wetland Habitat: The amount of wetland habitat lost varies with the intensity of ditching. In the most extensively ditched areas, up to 80 percent of historical wetland is replaced with ditch and spoil pile. On average, half of an impacted area is ditch and spoil. This reduces ecological productivity, which in turn reduces the fish and wildlife the area can support. The protection from storms that wetlands can provide also is diminished.

Invasion of upland and non-native species: Spoil areas are substantially higher elevations than the surrounding wetland. This elevation allows the colonization of upland plant species, including invasive non-natives like Brazilian peppers. The mangroves that remain inhabit a narrow intertidal zone along the edges of spoil piles, but often are out-competed by terrestrial and exotic species on the upper portion of the pile.

Loss of juvenile fish habitat: The wetlands lose plants, especially grasses, which are critical for providing food and shelter for fishes, crabs, and shrimps. The deep water provided by the ditches allows large fish predators access to what was historically shallow water habitat utilized by small juvenile and resident fish.

Restoring Dragline Ditches

Amphibious Excavator: The project uses a long-reach excavator mounted on a pair of tracked pontoons (see Figure 3). This low bearing weight machine (less than 2 lbs/sq. in.) is owned and operated by Volusia County Mosquito Control.

Figure 3.

Vegetation Clearing: Vegetation is cleared from the spoil area and placed in the adjacent ditch. This process avoids burning the plants and permanently sequesters the carbon they contain.

Excavation and Grading: Spoil material is moved to the side “fingers” of the ditch (see Figure 4, large arrows). If additional material remains, the main ditch is narrowed (see Figure 4, smaller arrows). The area of the spoil pile and the newly filled ditch are graded to the adjacent wetland elevation. The result is that substantially more area is at coastal wetland elevation.

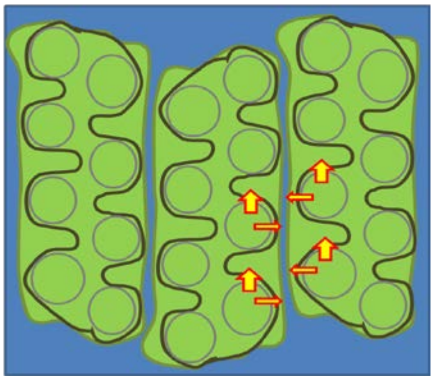


Figure 4.

Benefits of Dragline Ditch Restoration

Increased Wetland Habitat: To date, approximately 250 acres of impacted wetland have been restored returning approximately 100 acres to wetland elevation. Restored wetlands provide more space for wading and shore birds and greater production of fishes, crabs, and shrimps and the plants they depend upon. Restored wetlands can produce about 50 lbs of resident fish per acre per year.

Continued Mosquito Control: With the small relic ditches that remain after restoration, mosquito breeding has not increased in any of the previous project areas over the last eight years.

Native Wetland Plant Communities: Wetland plants recruit to the restored surface quickly. Early colonizers include black mangroves, sea purslane, and glasswort. Plants left on site and from neighboring wetlands provide recruits to the restored areas within months or years.

Increased Juvenile Fish Habitat: The restored wetland area and the relic shallow ditches are a perfect combination for fish productivity. The high levels of resident fish production from the restored wetland areas during the high water periods of the year and the shallow water access provided to juveniles of large fisheries species is a recipe for great fishing into the future.

Frequently Asked Questions

1. **How did the dragline ditch restoration effort come about and who has adopted / permitted it?**

The first pilot project was conducted in Canaveral National Seashore in 2000 by a team that included National Park Service, St. Johns River Water Management District (SJRWMD) and Volusia County Mosquito Control (VCMC). A second project was conducted in Tomoka State Park. Dragline ditch restoration was subsequently included in SJRWMD-developed Florida Department of Environmental Protection (FDEP)-approved Indian River Lagoon (IRL) and Northern Coastal Basins Surface Water Improvement and Management Plans. It was also included in EPA's IRL Comprehensive Conservation and Management Plan (National Estuary Program) and FDEP's Mosquito Lagoon Aquatic Preserve Management Plan. All of these planning efforts included input and comments from the public. Florida Fish and Wildlife Commission (FWC) Division of Habitat and Species Conservation is also fully supportive of this effort. These projects are implemented under environmental resource permits issued by FDEP and US Army Corps of Engineers in consultation with US Fish and Wildlife Service (FWS) and the NOAA's Habitat Conservation Division. Presentations about this and similar wetland restoration projects have been provided to homeowners, civic groups, county /city commissions, state/federal legislators, and organizations like the Sierra Club and Coastal Conservation Association.

2. **Who is responsible for the current restoration project?**This restoration effort is a partnership between the FWC, SJRWMD and VCMC. This team works with the managers of public lands to successfully restore these wetlands .

3. **How is this restoration effort being funded?**

Phase I of this restoration project is funded by regional, state and federal partnership money. VCMC is providing approximately $40, 000 of in-kind services (fuel, equipment maintenance, and field supervision). FWC and SJRWMD are supplying $220,000 of in-kind staff salary (grant and contract administration) and cash match (State and local sources). A federal grant of $520,000 provided to FWC by the National Coastal Wetlands Conservation Grant Program (administered by the FWS) supports the majority of the project's costs. This grant program is funded by federal excise taxes on fishing equipment and motorboat and small engine fuels. http://www.fws.gov/coastal/CoastalGrants/

4. **How much of the marsh system is being restored?**

There were about 1,200 acres of dragline ditch wetland in the Mosquito Lagoon region. The Volusia wetland restoration project is directed toward restoring 600 acres of this damaged system. Currently, Phase I of the project is funded, so roughly 300 acres will be restored using existing funds.

5. **What are the timelines for this restoration project?**

The current project was funded and initiated during 2009 and, given continued regional, state and federal funding, will be completed in 2013.