Atlantic States Marine Fisheries Commission

Habitat Committee

December 2, 2021

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Agenda

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

1.	Welcome and introductions (*J. Johnson*)	9:00 am
2.	Committee consent (*J. Johnson*) [Briefing material {BM} 1]	9:10
	• Approval of agenda	
3.	ACFHP update (*L. Havel*)	9:15
4.	Navigation and deepening project discussion (*M. Rousseau/L. Havel*)	9:30
5.	ASMFC involvement in offshore wind discussion (*T. Kerns*)	10:15
6.	Break	11:00
7.	Species assignments check-in (*L. Havel/T. Kerns*) [BM 2]	11:15
	• Topics of interest from Management Board meetings	
	• Upcoming addenda/amendments in need of habitat updates	
8.	Lunch break	12:00 pm
9.	Status Updates	1:30
	• SAV Policy/living shorelines (*L. Havel/L. Chiarella*) [BM 3, 4]	
	i. SAV definition	
	• Habitat Management Series: Acoustics (*L. Havel*) [BM 5]	
	• Climate Change Document	
	• Habitat Hotline (*L. Havel*)	
	• Fish Habitats of Concern (*L. Havel*) [BM 6]	
10.	Other Business (*J. Johnson*)	3:45
11.	Adjourn	4:00

BY COMMITTEE MEMBER

Member	Species Assignments
Russ Babb	spiny dogfish AND black drum
Michelle Bachman	Atlantic herring
Josh Carloni	Jonah crab AND American lobster
Lou Chiarella	coastal sharks
Jessica Coakley	summer flounder AND scup
Dave Dippold	American eel
Claire Enterline	Northern shrimp AND Atlantic herring
Ginny Fay	spotted seatrout
Alexa Fournier	weakfish AND tautog
Jimmy Johnson	red drum AND weakfish
Wilson Laney	striped bass AND American eel AND shad and river herring
Robert LaFrance	horseshoe crab, menhaden
Paul Medders	spotted seatrout AND red drum
Randy Owen/Tiffany Birge	shad and river herring
Mark Rousseau	horseshoe crab
Sharleen Johnson	spot AND Atlantic croaker
Eric Schneider	winter flounder AND Atlantic sturgeon
Graham Sherwood	Northern shrimp AND Atlantic herring
Kent Smith	Spanish mackerel AND cobia
Jeff Tinsman	tautog
Marek Topolski	black sea bass AND striped bass
Kate Wilke	bluefish AND menhaden

BY SPECIES

Species	Member
American eel	Wilson Laney AND Dave Dippold
American lobster	Josh Carloni
Atlantic croaker	Sharleen Johnson
Atlantic herring	Michelle Bachman, Graham Sherwood, Claire Enterline
Atlantic sturgeon	Eric Schneider
black drum	Russ Babb
black sea bass	Marek Topolski
bluefish	Kate Wilke
coastal sharks	Lou Chiarella
cobia	Kent Smith
horseshoe crab	Mark Rousseau AND Robert LaFrance
Jonah crab	Josh Carloni
menhaden	Kate Wilke AND Robert LaFrance
Northern shrimp	Graham Sherwood AND Claire Enterline
red drum	Jimmy Johnson AND Paul Medders
scup	Jessica Coakley
shad & river herring	Wilson Laney AND Randy Owen/Tiffany Birge
Spanish mackerel	Kent Smith
spiny dogfish	Russ Babb
spot	Sharleen Johnson
spotted seatrout	Ginny Fay AND Paul Medders
striped bass	Marek Topolski AND Wilson Laney
summer flounder	Jessica Coakley
tautog	Alexa Fournier AND Jeff Tinsman
weakfish	Jimmy Johnson AND Alexa Fournier
winter flounder	Eric Schneider

US Army Corps of Engineers®
Seattle District

COMPONENTS OF A COMPLETE EELGRASS DELINEATION AND CHARACTERIZATION REPORT

May 27, 2016

Contents

PREFACE

This document was developed by Dr. Deborah Shafer Nelson, U.S. Army Engineer Research and Development Center at the request of the Seattle District and Headquarters, U.S. Army Corps of Engineers, with funding provided through the Wetlands Regulatory Assistance Program.

Purpose

This document provides technical guidance and procedures for identifying and delineating eelgrass (*Zostera* spp.) that may be subject to regulatory jurisdiction under Section 404 of the Clean Water Act (33 U.S.C.1344) or Section 10 of the Rivers and Harbors Act (33 U.S.C.403). It has been developed to assist applicants and/or their consultants within the geographic area covered by the Seattle District U. S. Army Corps of Engineers when a characterization of eelgrass is requested to evaluate proposed work within marine waters. Note: This document was developed for eelgrass; however, we encourage the user to document other marine species, such as kelp, as that information may be required for the overall characterization of the project site. Also, although this guidance is specifically for eelgrass, it may be applicable for other types of seagrasses.

Qualifications

Eelgrass mapping and monitoring surveys should be performed by someone who has demonstrated the ability to identify eelgrass species present within the project area, and conduct ecological surveys.

Survey Timing

Sampling shall be conducted during periods when above-ground material is present in sufficient quantities to be readily observable: June 1 through October 1. If multi-year surveys are planned, they should all be done at the same time of year to avoid seasonal biases in the results. Survey results will be valid for a period of 1 year. If it has been more than 1 year but less than 3 years since the last survey, then at a minimum, the mapped boundaries of the eelgrass and macroalgae beds must be re-verified to ensure that they have not changed. If more than 3 years have elapsed since the last eelgrass/macroalgae mapping survey, a new complete mapping survey shall be conducted.

Overview of Eelgrass Survey Types: Tier 1 and Tier 2

Depending on the type and scale of the proposed project, either a Tier 1 level eelgrass survey or a Tier 2 survey is recommended. The requirements for Tier 1 and Tier 2 surveys are described in detail in subsequent sections.

Tier 1: survey is considered a reconnaissance level survey that captures basic information such as presence/absence and eelgrass bed spatial distribution. A Tier-1 survey is generally applicable when the project will avoid work in eelgrass and therefore only requires identification of the eelgrass boundaries.

Tier 2: survey is intended to be a more rigorous quantitative characterization for work with the potential for direct impacts to eelgrass resources and is generally applicable to projects such as dredging, commercial-scale marinas, large aquaculture projects, cable and pipeline installation projects involving trenching and filling, and construction of small-scale ocean energy structures (e.g., tidal or wave energy, wind energy). For large projects, it may be more efficient to use a combination of Tier 1 and Tier 2 surveys. Tier 1 reconnaissance surveys conducted over large areas can be used to target specific areas where more detailed eelgrass resource maps may be needed.

Defining and Delineating Eelgrass Bed Boundaries

The uppermost boundaries of seagrass growth are controlled by desiccation and temperature stress (Boese et al. 2005), but can also be locally influenced by activities such as shellfish harvest and reflective energy from shoreline armoring (Short and Wyllie-Echeverria 1996). The lower boundary, or maximum depth of seagrass growth can be directly related to the submarine light environment (Duarte 1991). Within these limits, seagrass bed patterns range from continuous or semi-continuous over hundreds of meters to patchy distributions ranging from a meter to tens of meters in the longest dimension (Fonseca and Bell 1998).

Potential *Z. marina* habitat in the Pacific Northwest may be classified as either fringe or flats based on its geomorphic setting (Berry et al. 2003). Fringe *Z. marina* habitats are areas with relatively linear shorelines where potential *Z. marina* habitat is limited to a narrow band by bathymetry. Identification of eelgrass bed boundaries in fringe sites is relatively straightforward. Flats *Z. marina* sites are shallow embayments with extensive broad shallows that appear to have little slope within the vegetated zones. Delineation of eelgrass beds in flats sites can be more challenging because they are often highly fragmented and very dynamic on both spatial and temporal scales. Bed patchiness increases with increasing wave exposure and tidal current speed. For more information on the influence of landscape setting and physical exposure on eelgrass bed configuration, see Appendix A.

One of the two methods described below shall be used to define eelgrass habitat and delineate eelgrass bed boundaries. Although the two methods are slightly different, in practice the results of eelgrass delineations done with either method would be expected to be similar[1].

If the eelgrass bed is composed of many individual patches, and the distance between adjacent patches is 5m or less, then it is not necessary to delineate each individual patch. The outer perimeters of the patchy areas may be delineated as described below and noted as patchy on the site description.

Eelgrass Delineation Method A: An eelgrass bed is defined as a minimum of 3 shoots per 0.25 m^2 (1/4 square meter) within 1 meter of any adjacent shoots. To identify the bed boundary, proceed in a linear direction and find the last shoot that is within 1 meter of an adjacent shoot along that transect. The bed boundary (edge) is defined as the point 0.5 meter past that last shoot, in recognition of the average length of the roots and rhizomes extending from an individual shoot (Washington Dept. of Natural Resources (WADNR) 2012).

Eelgrass Delineation Method B: *The California Eelgrass Mitigation Policy and Implementing Guidelines* (NOAA Fisheries 2014) identify eelgrass bed edge as follows: any eelgrass within one square meter quadrat and within 1 meter of another shoot.

[1] In cases where the delineation is part of the support for a proposed permit, is required to meet programmatic Endangered Species Act consultations, or as proposed mitigation, the appropriate buffer should be included in maps/drawings. Once the bed edge is identified using either Method A or B, delineate an un-vegetated perimeter zone around the edge of each bed or patch. Un-vegetated areas within this perimeter zone may have eelgrass shoots a distance greater than 1 meter from another shoot, and may be internal as well as external to areas of vegetated cover. See Figure 1 in Appendix A for example. The required width of the un-vegetated perimeter may vary by project type. Applicants should also be aware of local and state requirements for eelgrass surveys, as these may differ from the guidance presented here. In that case, identify the larger perimeter zone.

Tier 1 Surveys

A Tier 1 survey is considered a reconnaissance level survey for those projects that propose to avoid work in eelgrass. A Tier 1 survey captures basic information such as presence/absence, eelgrass bed spatial distribution, including maximum and minimum depth distribution, approximation of the total area of the eelgrass bed, and a qualitative assessment of eelgrass cover. Appendix B provides a sample data sheet and eelgrass habitat map suitable for Tier 1 surveys.

Tier 1 Data Collection Methods.

Intertidal sites shall be sampled by walking or wading during low tides. Divers will usually be needed to collect information at subtidal sites.

For very large sites, alternative remote sensing methods such as underwater photography, hydroacoustic surveys or aerial photography may be used to determine eelgrass bed locations. For more information on these methods, see the section on Eelgrass Survey and Mapping Methods. However, if any of these remote sensing methods is used to prepare maps of eelgrass distribution, additional data must also be collected (and submitted) using walking, wading or diver surveys to verify the remotely sensed data.

Tier 1 Transect Layout.

For linear projects (e. g. pipelines), establish a single transect aligned along the centerline of the project footprint. Otherwise, establish a series of sample transects perpendicular to shore spaced between 5 to 25 feet apart. For projects that are not adjacent to the shoreline, orientate transects relative to another physical reference, such as a channel boundary or depth gradient. Transects must also be referenced to a permanent feature at the site to ensure repeatability.

At sites where the eelgrass beds are smaller, with patchy or discontinuous distributions, sample transects should be closely spaced (5 to10 feet). For sites containing relatively contiguous eelgrass beds, or for projects involving very large areas, transects spaced at intervals of 15 to 25 feet apart are appropriate. At least one transect should be aligned along the proposed centerline of the project. Locate additional transects at distances of 10 and 25 feet from the outer edges of the proposed project footprint. Transects should extend at least 25 feet waterward of the project footprint, or to the outer margin of the eelgrass bed.

Along each transect, determine the location of the boundaries of the eelgrass beds or patches according to the instructions for either Method A or B for delineating the boundaries of eelgrass habitats. Applicants are also encouraged to note the location of any macroalgae, especially kelp species, if present.

Tier 1 Field Data Collection and Reporting.

The following data shall be recorded in the field and included in the survey report:

1. Site name, sample date and time of day (start and finish);
2. The names of the person(s) conducting the survey; and whether Method A or Method B was used to delineate the eelgrass bed(s).

For each survey transect, record the following information:

3. Record the GPS coordinates, elevation (relative to mean lower low water (MLLW)), and distance along the transect of the upper and lower boundaries of the eelgrass and macroalgae beds or patches, by species. **NOTE:** If dwarf eelgrass (*Zostera japonica*) is present, there may be multiple eelgrass zones (e.g. an upper intertidal zone of pure *Z. japonica*, a mid-intertidal zone of *Z. japonica* mixed with *Z. marina*, and a pure *Z. marina* zone). In this case, record the GPS coordinates, elevation (relative to MLLW) and distance along transect for the upper and lower boundaries of each zone along each survey transect In mixed beds, it can sometimes be difficult to distinguish between the two *Zostera* species. For further information on identification of *Z. marina* and *Z. japonica*, see Appendix C.
4. Using either a 0.25 square meter (Method A) or 1.0 square meter quadrat (Method B) , record estimates of eelgrass and macroalgae percent cover, by species, along each transect at intervals equal to the transect spacing, forming a sample grid pattern. For example, if the transects are spaced 10 feet apart, record species' percent cover in sampling stations at 10-foot intervals along the transects. In addition, record species' percent coverage at both the beginning and end of each transect. Categorical estimates of percent cover may be used [e.g, absent or 0%; 1-10% cover; 11-25% cover; 26-50% cover; and > (greater than) 50% cover].

5. Applicants are also encouraged to record notable biological observations (e.g., the presence of flowering eelgrass shoots, shellfish, crabs, fish, marine mammals, shorebirds or waterfowl, sediment type (e.g., silt, mud, sand, shell, etc).

Tier 1 Preparation of Habitat Maps.

Prepare an eelgrass and macroalgae habitat distribution map using the GPS coordinates taken from the survey data. The map shall include the following information:

a) Site name, sample date and times, names of the persons collecting the data;
b) Boundaries of the project area and site plan; and north arrow;
c) Accurate bathymetric contours (local vertical datum of MLLW) at intervals of not more than 1 foot;
d) Scale and measures of distance along the axis of the transects;
e) Locations of all sample transects and sampling stations;
f) Locations of upper and lower boundaries of *Z. marina* and *Z. japonica* (if present) eelgrass beds, and, if buffer proposed, an unvegetated perimeter around bed edges;
g) Estimated percent cover of eelgrass and macroalgae [e.g, absent or 0%; 1-10% cover; 11-25% cover; 26-50% cover; and > 50% cover] at each quadrat sample point.

Tier 1 Reporting Requirements.

In addition to the maps of eelgrass distribution within the project area described above, the report shall also include the following:

1) Calculations of total project acreage;
2) Calculations of eelgrass acreage (total area of all eelgrass beds and patches as defined previously; by species);
3) Calculations of eelgrass habitat acreage, by species
   For contiguous beds, eelgrass habitat acreage is the area of all contiguous beds, plus, if buffer proposed, the area of the un-vegetated perimeter around the bed edge.
   For patchy beds, eelgrass habitat area includes the cumulative area of the individual patches, including any un-vegetated areas between patches that are less than 16 feet (5 meters) apart, plus, if buffer proposed, the area of the un-vegetated perimeter

around the bed edge. Note that un-vegetated areas may include areas with single eelgrass shoots that are more than 1 meter apart.

4) Data sheets showing the information collected on each transect (see Example in Appendix A).
5) (Recommended) Notable biological observations (the presence of flowering eelgrass shoots, shellfish, crabs, fish, marine mammals, shorebirds or waterfowl, etc.

Tier 2 Surveys

A Tier 2 survey is intended to be a more rigorous quantitative characterization for work with the potential for direct impacts to eelgrass resources and is generally applicable to larger-scale projects, such as dredging, commercial-scale marinas, large aquaculture projects, cable and pipeline installation projects involving trenching and filling, and construction of small-scale ocean energy structures (e.g., tidal or wave energy, wind energy).

Tier 2 surveys should be designed to be replicated, because multi-year surveys may be required to establish baseline conditions in some sites, and post-construction surveys may be required to determine the extent of potential eelgrass impact or be used to monitor the success of eelgrass compensatory mitigation projects.

It is important to note that the spatial scale of large coastal development projects can have potentially larger impacts on eelgrass and may require more extensive site analysis and evaluation than is presented in this guidance. Likewise, compensatory mitigation projects involving eelgrass may require environmental assessments beyond the scope of this guidance. Applicants should also be aware of local and state requirements for eelgrass surveys, as these may differ from the guidance presented here.

Tier 2 Transect Layout.

For linear projects (e. g. pipelines), establish a single transect aligned along the centerline of the project footprint. Otherwise, establish a series of sample transects perpendicular to shore at the appropriate spacing, typically 5 to 16 feet (2 to 5 meters) apart. Transect spacing for Tier 2 surveys will generally be closer than for Tier 1 surveys. For projects not adjacent to the shoreline, orientate transects relative to another physical reference, such as a channel boundary or depth gradient. Transects must also be referenced to a permanent feature at the site to ensure repeatability. If multi-year surveys are being conducted to detect changes in eelgrass condition over time, or assess potential impacts, the locations of sample transects shall be fixed, not random, and should be permanently marked so that they can be sampled repeatedly over time.

Tier 2 surveys, maps and reports shall include all of the information identified above for a Tier 1 survey.

In addition, Tier 2 surveys shall include quantitative quadrat sampling for eelgrass density as described below. Along each transect line, place a 0.25-m^2 (1/4 square meter) or 1.0 m^2 (1 square meter) quadrat sampling frame at intervals equal to the transect spacing, forming a sample grid pattern. For example, if the transects are spaced 5 feet apart, place the quadrat sampling frame at 5-foot intervals along the transect. Placement of the quadrat relative to the transect line at each sampling station may be done randomly (e.g., coin toss) or by consistently placing the quadrat on one side or the other for all sampling stations. Quantitative sampling of eelgrass shall be limited to areas no deeper than the deepest natural eelgrass patch found in the vicinity of the project.

For each quadrat sample location, native eelgrass (*Z. marina*) shoot density (number of native eelgrass shoots present in the quadrat sampling frame) shall be recorded. If 0.25 m^2 sample quadrats are used, then raw data values of eelgrass shoot density shall be converted to numbers of shoots per m^2 (square meter). For non-native eelgrass (*Z. japonica*) or macroalgae, categorical estimates of percent cover [e.g, absent or 0%; 1-10% cover; 11-25% cover; 26-50% cover; and greater than 50% cover] may be recorded in lieu of shoot density for each quadrat sample. A minimum of thirty samples per site will be taken within the eelgrass or macroalgae zone.

Eelgrass Survey and Mapping Methods

Method 1: Walking or Wading (Tier 1 and 2)

This method should be used if the site is intertidal. The shallow, or inshore, edge of the bed is usually clearly visible at low tide. At each site, establish a series of transect lines according to either Tier 1 or Tier 2 survey methods. An observer with a handheld Geographic Positioning System GPS unit shall walk or wade along each transect and record the locations of the upper and lower boundaries of eelgrass beds or zones, using either Method A or B for delineating the boundaries of the eelgrass beds. If the water is clear, the deep or offshore edge of the eelgrass bed may be visible with the naked eye from the boat or with the use of a bathyscope (underwater viewing box). GPS coordinates and water depth can be taken according to either Tier 1 or Tier 2 survey methods to track the deep edge of the bed.

Method 2: Snorkelers or Divers (Tier 1 and 2)

If the water, even at low tide, does not allow observation of the bottom, then snorkelers or divers shall be used to identify the boundaries of any eelgrass present onsite. Safety issues such as the potential for strong tidal currents in some areas should also be considered.

For Tier 1 surveys, a series of buoys can be used to mark the upper and lower edges of the bed to identify their locations. The scope, or length, of the line on the buoy needs to be minimized to the greatest extent possible. Having a large amount of scope on the line can lead to significant under/overestimate of actual eelgrass extent. Once the boundaries are marked with buoys, then a vessel can be maneuvered from buoy to buoy recording GPS coordinates.

Tier 2 surveys will require a series of quantitative samples along transects using 0.25 m^2 or 1.0 m^2 quadrats (see Tier 2 methods above).

Method 3: Underwater Photography (Tier 1 only)

Underwater videography can be particularly useful for detecting and mapping the presence of eelgrass over large study areas that may be difficult to sample using more intensive methods such as diver transects. At each site, establish a series of transect lines running perpendicular to the shoreline that begin just outside the boundaries of the proposed project area, making sure that the transects cover the entire project area. Record underwater imagery along each transect and identify the locations of all visible eelgrass beds or patches. However, it may not always be possible to distinguish among Pacific Northwest seagrasses (e.g. *Z. marina*, *Z. japonica* and *Phyllospadix* spp.) (Berry et al. 2003). Where multiple seagrass species occur, verification shall be performed using Methods 1 or 2 above to verify species identification.

Method 4: Hydroacoustic Mapping (Tier 1 only)

If the site is very large, hydroacoustic surveys may be considered as an alternative to the methods outlined above for a Tier 1 survey. Because detection and mapping of eelgrass using hydroacoustic equipment is not limited by water clarity, this method is particularly suitable for turbid water conditions. Depending on the heterogeneity of the eelgrass beds, the size of the area, and the desired degree of survey resolution, transect spacing may vary from as little as 25 ft to more than 100 ft. However, ground-truthing using wading, divers, or underwater photography must be performed to verify the hydroacoustic mapping classifications.

Limitations: Hydroacoustic surveys are not suitable for very shallow waters (less than 0.75 m) where access by small boats is limited. The hydroacoustic survey system is not currently capable of reliably distinguishing between underwater vascular plants (e.g. eelgrass) and macroalgae (e.g., kelp). In tidal waters, the information on canopy height is unreliable unless the surveys were conducted at slack tide.

Method 5: Aerial Photography (Tier 1 only)

If the site is extremely large, aerial photography obtained from the state or other sources may be used to provide background information on the likely presence or absence of eelgrass at a particular site. However, it shall not be used as the only source of information. It is not possible to reliably distinguish between eelgrass and macroalgae, or between different species of eelgrass or other seagrasses, using aerial imagery. Aerial photography is also likely to underestimate eelgrass coverage because eelgrass occurring in deeper waters can appear dark and may not be detected. Ground-truthing using any of Methods 1through 3 above must be performed to verify the mapping classifications determined from aerial photography.

APPENDIX A : THE INFLUENCE OF LANDSCAPE SETTING ON EELGRASS BED CONFIGURATION

Shallow eelgrass populations form characteristic landscapes with a configuration that is highly related to the level of physical exposure. Seagrass bed patterns range from continuous or semi-continuous over hundred of meters to patchy distributions ranging from a meter to tens of meters in the longest dimension (Fonseca and Bell 1998). Bed fragmentation generally increases with increasing wave exposure and tidal current speed (Fonseca and Bell 1998). Therefore, the geomorphic setting and hydrodynamics of the nearshore zone have a strong influence on seagrass distribution and bed structure.

Potential *Z. marina* habitat in the Pacific Northwest may be classified as either fringe (Figure 1) or flats (Figure 2) based on its geomorphic setting (Berry et al. 2003). These classifications are analogous to the tidal fringe and flats classes of wetlands in the Hydrogeomorphic (HGM) wetland classification system (Smith et al. 1995).

2.1 Fringe Eelgrass Habitats

Fringe *Z. marina* habitats are areas with relatively linear shorelines where potential *Z. marina* habitat is limited to a narrow band by bathymetry. Fringe eelgrass beds may be contiguous or nearly contiguous over long sections of linear shorelines (Figure A1). The fringe category is further classified into narrow fringe and wide fringe based on a 305 m (1000 ft) threshold width separating ordinary high water and the –20 ft depth contour (Berry et al. 2003) (Figure A1).

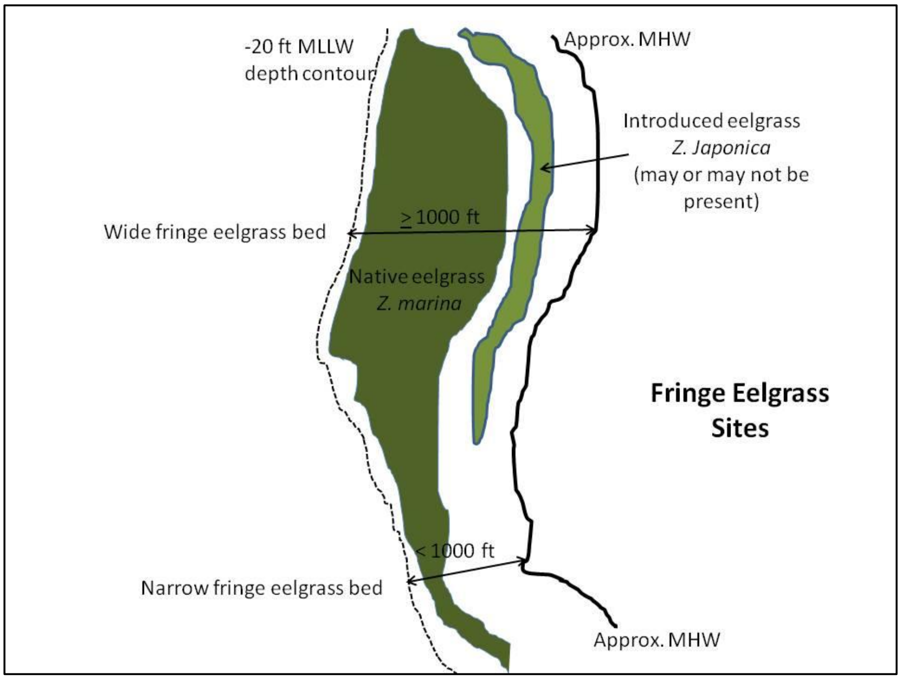


Figure A1. Illustration of fringe geomorphic classifications of eelgrass sites (modified from Berry et al. 2003).

2.2 Flats Eelgrass Habitats

Flats *Z. marina* sites are shallow embayments with extensive broad shallows that appear to have little slope within the vegetated zones. Slightly more than half of the total area of *Z. marina* habitat in Puget Sound is characterized as flats; one large embayment, Padilla Bay, contains approximately 20% of the *Z. marina* in Puget Sound (Berry et al. 2003). Flats sites may be further sub-classified into river-influenced flats such as river deltas, and tide-influenced flats (pocket beaches and other sites that lack a significant source of freshwater and associated sediment input) (Figure A2). Periodic pulses of sediment in river- influenced flats sites may generate shallow shoal complexes that can be highly dynamic over timeframes of months to years, leading to a continually changing mosaic of eelgrass patches interspersed with unvegetated shoals (Marbà et al. 1994).

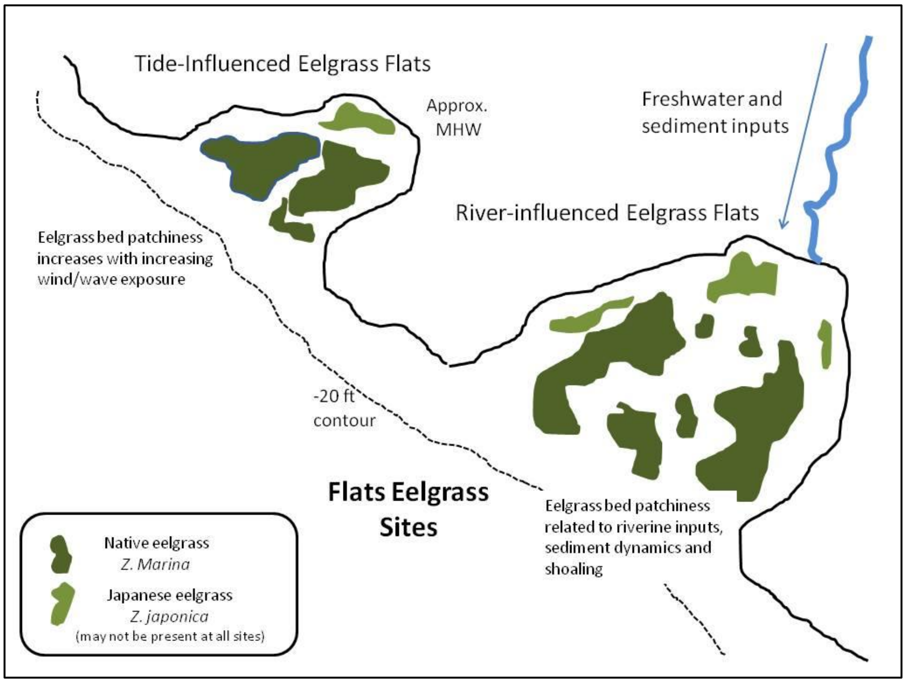


Figure A2. Illustration of flats geomorphic classifications of *Z. marina* habitats (modified from Berry et al. 2003).

3.0 SPATIAL AND TEMPORAL VARIATION IN EELGRASS BED LOCATION

Within eelgrass habitat, eelgrass is expected to fluctuate in density and patch extent and can expand, contract, disappear, and re-colonize areas within suitable environments based on prevailing environmental factors (e.g., turbidity, freshwater flows, wave and current energy, bioturbation, temperature, etc.). Because the maximum depth of seagrass colonization is controlled by light availability, tracking the deep edge of growth can provide information on the quality of the estuarine light environment over time relative to local and regional water quality standards. Upslope movements (deep → shallow) in the location of the deep bed edge have been used as an indicator of some type of chronic disturbance, either natural or anthropogenic, that results in increased turbidity and reduced light availability for seagrasses.

Eelgrass meadows in Puget Sound are characterized by substantial interannual variability that appear to be related to the occurrence of El Niño climate events, emphasizing the importance of multi-year surveys to adequately characterize seagrass abundance and distribution in a particular area (Nelson 1997). Vegetated eelgrass areas on the Pacific coast can expand by as much as

5 meters (m) and contract by as much as 4 m annually (Washington Dept of Natural Resources 2012). To account for these normal fluctuations, Fonseca et al. (1998) recommends that seagrass habitat include the vegetated areas as well as presently unvegetated spaces between seagrass patches.

Patterns in eelgrass bed 'patchiness' or fragmentation are related to the degree of exposure to disturbance from wind, waves and tidal currents. Wind-generated wave dynamics and tidal currents create sediment movement, which may either bury plants, expose roots and rhizomes or during heavy storms even uproot entire plants (Kirkman and Kuo 1990). Plant burial was found to be an important mechanism of gap formation in a seagrass system in Tampa Bay, USA (Bell et al. 1999) and the patch dynamics of *Zostera marina* vegetation in Rhode Island, USA was likewise thought to be controlled by sediment movement (Harlin and Thorne-Miller 1982).

Eelgrass patches may be constantly moving even during periods when a relatively constant total eelgrass area suggests stable conditions in the population. For example, although the total area of eelgrass was quite stable in the 1980s in Amager, Denmark, where a complex system of alternating eelgrass belts and sandbars is found, about 55 % of the eelgrass changed between two consecutive mappings (Frederiksen et al. 2004). The mechanism behind is probably that extrinsic disturbance factors constantly change growth conditions in the exposed areas and keep the eelgrass populations in a state of continuous re-colonization. The maps showed that the eelgrass belts migrated in a northeasterly direction and the sandbars migrated in the same direction. Outer sandbars feed the inner sandbars with sediment and substantial transportation of sand thus occurs along the sandbars (Frederiksen et al. 2004). This sediment movement most likely led to either burial or erosion on the western edges of the eelgrass patches and new growth mainly occurred in the eastern parts. Similar patterns have been observed in the eelgrass beds associated with a flood tide delta in Rhode Island, USA (Harlin and Thorne-Miller 1982), and in Tillamook Bay, OR. Comparison of historic eelgrass maps and aerial imagery in Tillamook Bay suggests that eelgrass associated with shallow sandy shoals may have become buried or eroded over time, then became re-established in different locations as the shoals shifted in response to current or sediment pulses (Figure A3). Other areas in the Pacific Northwest that exhibit this pattern include eelgrass beds near the mouth of the Dungeness River in northern Washington.

Figure A3. Historic maps of eelgrass distribution on river-influenced flats in Tillamook Bay, OR (shown as light green polygons) superimposed on more recent aerial photography, showing apparent changes in the location of the eelgrass beds over time in an area with dynamic sediment movement and shoaling.

APPENDIX B: Example Data Sheet and Eelgrass Habitat Maps for Tier 1 Surveys

Site:		**Date:**			**Observers:**
Transect No. X		**Start Time:**			**Stop Time:**
GPS Positions:		**Transect Start:**			**Transect End:**
Eelgrass Boundaries		**Upper:**			**Lower:**
Station	Distance (m or ft)	% Cover Species Present *Z. marina*	*Z. japonica*	Macroalgae	Notes
1	2			25	Ulva Substrate: sand/shell
2	7		10	15	Upper boundary of *Z. japonica* zone
3	12		45	20	
4	17		60		Substrate: sand
5	22		45		
6	28		80		
7	35	5	60		Upper boundary of mixed *Z. marina and Z. japonica* zone
8	40	20	50		
9	43	50	10		Lower boundary of mixed *Z. marina* and *Z. japonica* zone
10	45	55			Upper boundary of *Z. marina* zone
11	50	70			
12	55	80			Dense Z. marina, flowering shoots present
13	60	65			Substrate: muddy sand

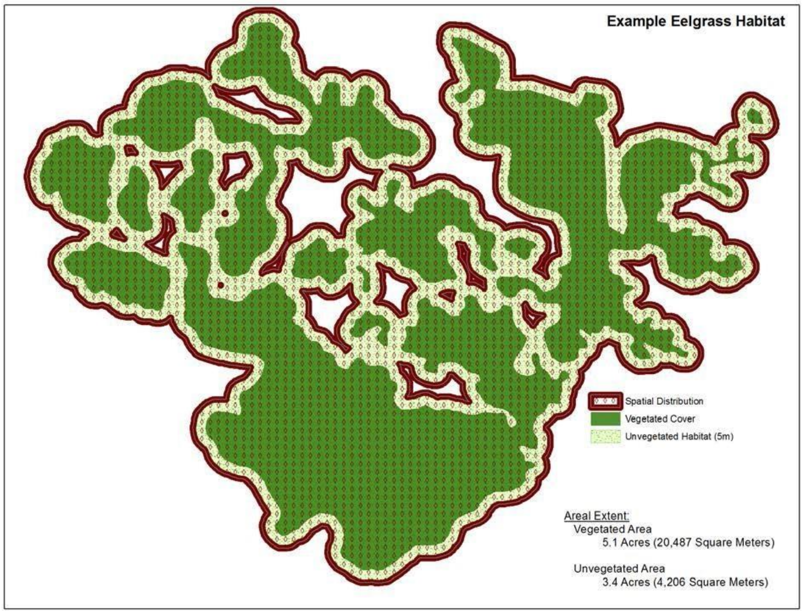


Figure B1. Graphic depiction of eelgrass habitat definition including spatial distribution and aerial coverage of vegetated cover and unvegetated eelgrass habitat (from NOAA Fisheries 2014; California Eelgrass Mitigation Policy and Implementing Guidelines).

APPENDIX C : Identification of *Zostera marina* and *Zostera japonica*

Zostera marina (eelgrass) Status: Native

Habitat: marine to brackish waters, lower intertidal and shallow subtidal; sandy to muddy sediments.

Zostera marina is the most widely distributed seagrass in the world. It's range spans the area from Alaska to California on the West Coast and is also found on the North American East Coast, Europe, Asia, and the Middle East. Common in low intertidal and subtidal zones to a depth of 20-30 feet along sheltered areas with sandy or muddy beaches. Leaf blades are usually about ½ inch (8-10 mm) wide but may be narrower. The blades reach a length of 10 ft (3 m) and are flat. This species blooms from June through August. The inflorescence (flower clusters) grow on the tips of long shoots separate from the leaf blades.

Ecology: Eelgrass habitats play an important role as foraging habitat for juvenile salmonids, particularly chum and Chinook. Pacific eelgrass stands also provide habitat for other important fishes and shellfish including Dungeness crab, starry flounder, and sturgeon. Spawning Pacific herring utilize eelgrass as a substrate to deposit eggs. Pacific eelgrass beds also harbor species of infauna and epifauna including polychaetes, gastropods, bivalves, amphipods, echinoderms, and other crustaceans that are known prey of many commercially valuable fish and invertebrates. Eelgrass meadows are also important foraging habitats for many species of migratory geese, ducks, and swans. Pacific Black Brant feed almost exclusively on eelgrass (both native and introduced) and their populations can be affected by declines in eelgrass abundance. Eelgrass leaves, roots, and rhizomes attenuate wave energy and provide shoreline stabilization. Eelgrass beds also sequester carbon and may play a role in minimizing the effects of ocean acidification, thus helping to mitigate the effects of global climate change.

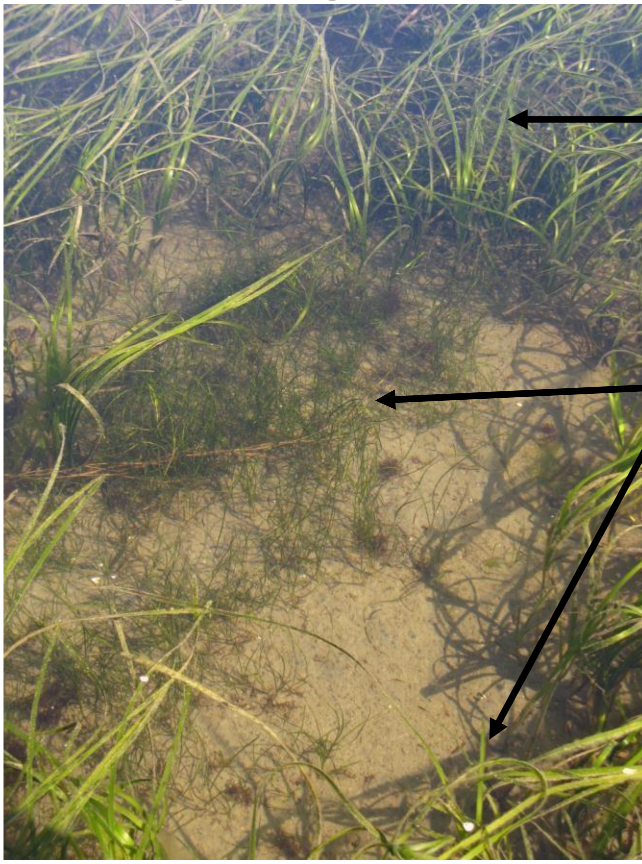
Zostera japonica (dwarf eelgrass) Status: Introduced

Habitat: marine to brackish waters, lower intertidal and shallow subtidal; sandy to muddy sediments. It typically occupies the upper to mid-intertidal zone at a higher elevation than the native eelgrass, *Z. marina*.

Z. japonica forms dense stands in shallow, sheltered bays and estuaries. In its native range, it occurs from Korea and Japan northward to the Kamchatka Peninsula in Russia. In North America, this species ranges from southern British Columbia to Humboldt Bay, California, and is expected to continue expanding its range. In the northern part of its range in North America (British Columbia), *Z. japonica* lives as an annual, overwintering as buried seeds. Towards the southern part of its established range in North America, it occurs as a short-lived perennial. It is listed as a Class C noxious weed in California and Washington, but is not listed on the federal invasive species list. It reproduces vegetatively through rhizomatous cloning and sexually through seed production. The habitat structure provided by this species may perform similar functions as native eelgrass; in particular, additional research is needed to verify its role in fisheries species utilization. This species is known to be an important food source for many species of migratory waterfowl, especially Pacific Black Brant. The dispersal of the seeds, both within and between estuaries, may be aided by waterfowl species.

Den Hartog, C. 1970. The Sea-Grasses of the World. North-Holland Publishing Company. Amsterdam, Netherlands. 272 pp.

Distinguishing Native and Introduced Eelgrass



Zostera marina

Native Eelgrass

(typical)

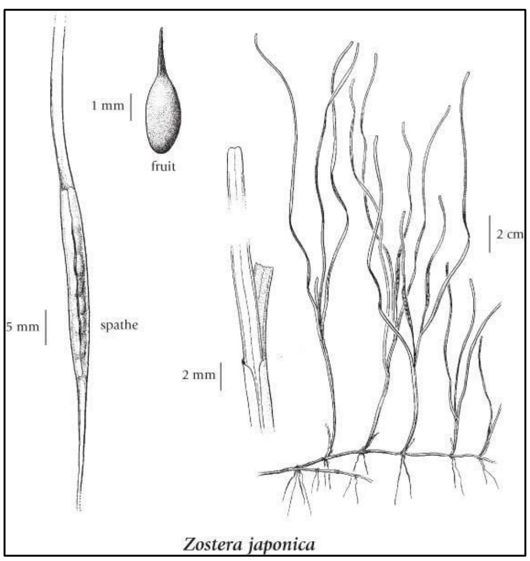
Zostera japonica

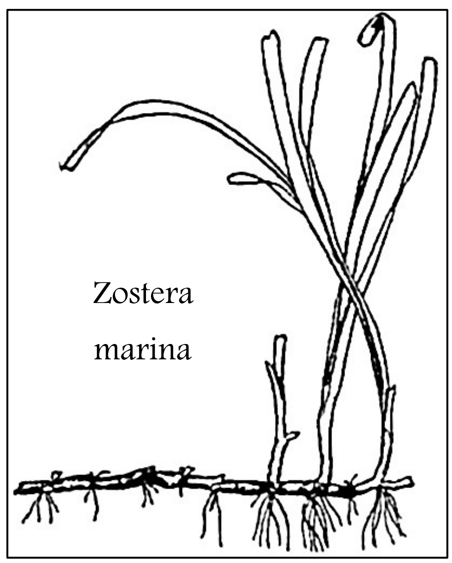
Japanese eelgrass

Introduced

IMPORTANT:

Leaf size is NOT a reliable indicator.
Z. marina **can sometimes look very similar to** ***Z. japonica*****!**





DISTINGUISHING CHARACTERISTIC
Z. japonica **has roots in pairs at each rhizome node.**
Z. marina **has roots in bundles at each rhizome node.**

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Appendix J
Technical Memorandum: Operational Definition of an Eelgrass *(Zostera marina)* Bed

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Appendix J. Technical Memorandum: Operational Definition of an Eelgrass *(Zostera marina)* Bed

Introduction

Proposed habitat conservation measures aimed at minimizing or avoiding impacts to eelgrass (*Zostera marina*) are currently being discussed among representatives of Washington's shellfish aquaculture industry and management and aquatics program staff of the Washington State Department of Natural Resources (Washington DNR). Questions have emerged from these discussions regarding what constitutes an edge of eelgrass bed: What minimum presence of eelgrass shoots comprise the edge of a bed? Are groups of non-contiguous eelgrass presence considered the edge of one larger bed, or are they treated as independent bed edges? Is there a minimum time during which observable shoots must persist in an area to be considered a bed? The answers to these questions will have direct effects on activities that are constrained because of their proximity to eelgrass beds.

In an effort to address these questions, a technical workgroup was convened with the goal of establishing criteria for defining an eelgrass bed. Workgroup participants included scientists and technical representatives from the Washington DNR Aquatics program, U.S. Fish and Wildlife Service, NOAA Fisheries, University of Washington, Northwest Indian Fisheries Commission, Point-No-Point Treaty Council, Squaxin Island Tribe, and shellfish aquaculture industry. This technical memorandum summarizes the information discussed at the meetings, reviews analyses of available data, proposes criteria for defining an eelgrass bed, and recommends metrics that should be considered when developing conservation measures with the intent to minimize and avoid impacts to eelgrass beds.

Goal

The overall goal is to determine the criteria for an operational definition of the minimum presence of eelgrass necessary to be considered a bed edge. The definition must be sufficient for site-level application for the sustainable management of eelgrass. It must allow for repeatable delineation of the beds, so that any impacts from activities authorized by Washington DNR in marine tidelands can be avoided or minimized with the application of appropriate conservation measures.

Objectives and constraints

- The eelgrass edge criteria must be applicable at the project or site scale (on the order of 0.1–10 acres). This definition must be precise enough to provide a basis for siting of projects on state-owned aquatic land parcels where eelgrass is present.
- Experienced environmental scientists must be able to apply the criteria using common survey methods and equipment.
- While a definition based on ecological principles is preferable, in the absence of conclusive scientific evidence, an operational definition based on best available scientific information will suffice, so long as it is understood that this will be adaptively managed as information is gathered through implementation and monitoring.

Background

Currently used or proposed criteria for eelgrass presence and bed edge

In response to the accumulation of scientific evidence demonstrating the importance of eelgrass to nearshore ecological function, entities tasked with sustainable stewardship of coastal habitats are striving to maintain and restore eelgrass (Orth et al., 2006; Phillips, 1984; Thom et al., 2008). This challenge requires the ability to delineate beds and to measure current status and change in the edge over time. Table 1 summarizes various eelgrass bed and edge criteria and identifies the agency or entity that has implemented or proposed each. Some of these definitions are proposed based on local empirical data; others are based on knowledge of a specific ecological function of the eelgrass (e.g. fish refugia). Some were developed for research or resource management purposes, while others were developed for regulatory implementation.

Table 1. Existing criteria for defining eelgrass presence and bed edge.

Implementation agency, entity, rule, or policy	Contiguous bed and bed edge criteria
Washington DNR Habitat Stewardship—Eelgrass Surveying Criteria	Contiguous separation distance ≤ 1 m. Minimum shoot density 3 shoots/m^2.
Washington DNR Submerged Vegetation Monitoring Program	Any eelgrass presence within a 1-m^2 area along the length of a video transect that is continuously sampled at approximately 1-m intervals until no presence is detected. A single shoot within a 0.1-m^2 grab sample.
U.S. Army Corps of Engineers Regional General Permit-6	An area of tidal substrate supporting eelgrass covering a minimum of 25% of the substrate.
Tampa Bay Estuary Program—Proposed Definition	A *seagrass bed* is ≥ 10% cover within a 10–30-m long transect line. The *zone of eelgrass occurrence* is defined as 1 shoot/m^2 for at least 10 m along a line transect (Virnstein *et al.*, 1998).
Alaska Sea Grant	A *persistent patch* of eelgrass from qualitative observations requires ≥ 50 shoots/m^2 (Wyllie-Echeverria & Thom, 1994).
Massachusetts Division of Marine Fisheries	The *edge of the bed* is defined as having two points: 1) the distance to the end of the continuous meadow and 2) the distance to the last shoot (Evans & Leschen, 2010).
Seagrass Net	To be considered within the same bed, any eelgrass present within a 1-m^2 quadrat must be within ≤ 1 m distance of a nearby eelgrass presence. The edge or transition area is indicated by the distance of the furthest eelgrass shoot that is beyond this 1-m contiguous bed from a fixed point along a fixed transect. Eelgrass shoot counts (within 0.0625 m^2) and percent cover (in 0.25 m^2) is estimated in 12 randomly pre-selected quadrats along a 50-m transect (Short *et al.*, 2006).
Seagrass Watch	A single shoot within a 1-m^2 quadrat along a 50-m long transect constitutes presence. Both shoot counts and an estimate of percent cover are recorded (McKenzie *et al.*, 2003).
Ospar Commission	A *seagrass meadow* is defined as an area of at least 2 x 2 m covered in seagrass. If < 10 m exists between patches, they are considered of the same meadow. If a distance > 10 m exists between patches, they are of separate meadows (MARBIPP, 2006).

Scientific literature relevant to the definition of minimum eelgrass presence

When developing a scientifically based definition of the minimum eelgrass presence needed to constitute an edge, the following points should be considered.

- In many areas, eelgrass occurs as a compound grouping of non-contiguous areas. (Fonseca & Bell, 1998). A separation distance criterion must be established to determine how to group these non-contiguous areas.
- The minimum detectable quantity of eelgrass depends on the sampling method used, but most site-scale sampling methods are able to detect eelgrass to the individual shoot. A minimum threshold that constitutes an accepted eelgrass presence (e.g. single shoot, area of specified shoot density, or percent cover) must be defined.
- Eelgrass morphological structure consists of above-ground shoots as well as below-ground rhizomes. The below-ground portion of the plant is often of larger dimension and mass than the visible, above-ground portion.
- Eelgrass presence affects the scope of habitat provision (benthic invertebrates, fish, or birds) (Hirst & Atrill, 2008).
- Eelgrass presence parameters (area and density) affect the ability of eelgrass to stabilize sediment and trap suspended particulates (Koch, 2001).
- Eelgrass biomass, area, and density affect the level of primary productivity and the contribution of the eelgrass to the detrital food web.
- Persistence of the vegetated area is another issue: A minimum eelgrass presence may be needed for an eelgrass unit to remain present year after year. Interannual cross- and long-shore variability of seagrass bed edges has been documented (Frederiksen et al., 2004; Marbà & Duarte, 1995; Grette Associates, 2005, 2008, 2009).
- Resilience of the vegetated area is a factor: A minimum residual eelgrass presence or density may be required to re-establish an area after it has experienced a disturbance (natural or anthropogenic).
- Distances between eelgrass shoots affect seed dispersal and successful gene flow.

These considerations relating to eelgrass attributes are important in understanding the ecological function of an eelgrass bed. Scientific studies with specific metrics regarding ecological attributes and functions of eelgrass beds are summarized below. This information was reviewed and discussed in the workgroup meetings when the participants considered the development of criteria for determining the minimum size, density, and persistence of an eelgrass bed edge.

Habitat

- Fonseca *et al.* (1998) observed that eelgrass present in areas as small as 1–2 m^2 had greater numbers of fish, shrimp, and crab than adjacent unvegetated areas.
- A study comparing benthic infaunal biodiversity of *Zostera* vegetated patches (ranging in size from 0.24 m^2 to 17 m^2) and unvegetated intertidal substrate areas found that all *Zostera* patches supported a higher level of biodiversity than bare sand, and neither the patch size nor mean shoot density had any impact on the level of diversity (Hirst & Attrill, 2008).

- In the United Kingdom, Eelgrass fragmentation was examined for its role in benthic infauna community composition by comparing infaunal communities in a continuous 2.3 ha meadow to the composition of patches 6–9 m^2 (Frost *et al.*, 1999). Communities differed as a result of small changes in species abundance, but not in diversity; however, polychaetes generally associated with unvegetated habitats (such as *Magelona mirabilis*) were found to be more common in the fragmented bed than in continuous beds.
- Neither patch size, nor location of sampling within patches (edge or central) exerted as much influence on the infaunal community as sediment composition (Frost *et al.*, 1999). Total abundance did not differ between patch sizes in univariate analyses. Multivariate analyses, on the other hand, showed that the species that contributed most to the difference in assemblage composition between patches were more abundant at the edge. In particular, the nematodes *Capitella capitata* and *Spio filicornis*—species tolerant of random disturbance (stochastic events)—were more abundant in samples collected at the edge of beds than in samples collected from the interior of the beds.
- An examination of fish and amphipod abundance across seagrass areas (*Halodule wrightii*) ranging from 5 to 93 m^2 in size suggested no consistent relationship between faunal abundance and patch size (Bell *et al.*, 2001).
- Based on a study of varying eelgrass densities (140 to 660 shoots/m^2), no significant differences in the number of fishes sampled were detected between eelgrass plots (Wyllie-Echeverria *et al.*, 2002, as cited in Blackmon *et al.*, 2006).
- It has been shown that throughout the Puget Sound, eelgrass habitat is used by juvenile salmonids, but no indication of how this habitat is used based on the density and structure of the eelgrass beds has been provided (Blackmon *et al.*, 2006).
- Epibenthic faunal abundance was closely related to eelgrass presence and shoot development when unvegetated, transplanted, recently seed-colonized, and mature eelgrass habitats in North Carolina were compared (Fonseca *et al.*, 1990).
- Blue crab survival in the Chesapeake Bay was found to vary with the size and complexity of eelgrass patches (Hovel & Lipcius, 2001, as cited in Blackmon *et al.*, 2006). Juvenile blue crab density decreased as patch size increased, and greater habitat fragmentation improved blue crab survival, because the fragmentation resulted in an increase in seagrass edge habitat. Crab density was significantly lower, however, in isolated patches separated by large areas of unvegetated habitats.
- In a New Zealand study, seagrass patch variables (patch size, percent cover, and biomass) explained only 3–4 percent of the variation in benthic community, while landscape variables (fractal geometry, patch isolation) and wave exposure explained 62.5 percent of the variation in faunal abundance data (Turner *et al.*, 1999).

Sediment characteristics

- Both above and below ground, eelgrass structure contributes to sediment stabilization: Above-ground shoots have the capacity to reduce water flow, which lowers the velocity of the flow on the sediment substrate, thus reducing the amount of sediment that can be entrained and transported (Fonseca el al., 2006).
- Eelgrass acts as a sediment sink, with above-ground shoots trapping sediment and particulates from the water column and below-ground rhizomes and roots anchoring sediment. This can result in sediment accretion that changes the bathymetry, causing mounding in areas around seagrass (Walker, 1999).

- The capacity of eelgrass to accrete sediment increases with increasing patch size. The magnitude of slowing current velocity and accreting sediment is based on the density of the eelgrass shoots, hydrodynamic conditions of the area, and depth of the water column above the plants (Koch, 2001). Changes in physical conditions trap nutrients and stabilize habitats that are necessary for seagrass growth and recruitment. Elimination of newly developed small patches will slow or entirely inhibit the development of larger, more extensive patches (Kendrick et al., 2005).
- Patches as small as 0.3 m and 1.0 m along the axis of current flow were capable of significantly reducing the velocity of the current relative to bare mud-flat habitat (Fonseca & Koehl, 2006). Eelgrass has been shown to attenuate 43 percent of wave energy in a 1-m long vegetated transect (Fonseca & Cahalan, 1992).
- A significant difference in median grain size and sorting coefficient was observed when contiguous and fragmented eelgrass areas were compared, and median grain size was found to be the variable that best explains multivariate community patterns (Frost et al., 1999).

Primary productivity/contribution to food web

Seagrasses can act as short-term sinks for refractory carbon: 1–2 years for above-ground biomass and 4–6 years for below-ground biomass (Mateo, 2006). Eelgrass has the capacity to survive and maintain actively growing perennial populations even in its northern-most limit. It does this by storing excess carbohydrates in the rhizomes during the dark winter. There is, therefore, important ecological function being provided by below-ground structure that may be laterally distant from the visible above-ground shoots (Duarte et al., 2002).

Persistence

In plots established outside a continuous vegetated meadow, patch mortality was observed to decrease as the size (area) and age of the patch increased, and only patches with more than 32 shoots survived. The critical minimum patch area required for survivorship varied seasonally (Olesen & Sand-Jensen, 1994).

Fonseca and Bell (1998) found that eelgrass areas with less than 50-percent cover were less stable than those with greater percent cover.

Resilience

Compared with seedlings, surviving adult plants and small patches may contribute considerably to recolonization of a dieback area, as these plants have faster elongation and branching rates and a lower mortality rate than seedlings (Greve et al., 2005).

Reproduction

There are differences in the relative importance of sexual and clonal portions of eelgrass life history that must be considered when attempting to set management standards for protection and maintenance of genetic structure (Table 2).

Seed Dispersal Distance and Transport Time

- Ninety-five percent of pollination occurs within 15 m of the source. Eighty-three percent of seeds are dispersed within 5 m of the source and 100 percent within 50 m (Ruckelshaus, 1996).
- Pollen is viable for only 7–48 hours (de Cock, 1980; Cox et al., 1992).
- Once buried in sediment, seeds of eelgrass can remain dormant for one to two months (Moore et al., 1993).
- Reproductive shoots carrying maturing seeds can be carried by currents or consumed by water fowl and transported long distances (kilometers).
- Germination rates range between 5 and 20 percent, with 80 percent of the seedling's germination within a 5-m diameter of the source (Orth et al., 1994). Germination rates were found to depend not on seed-density, but on patch size (Orth et al., 2003).

Genetic Neighborhood

- In a study of genetic diversity and patch size, with patches ranging from 0.25 m^2 to 440 m^2, Ruckelshaus (1996) found that genetic diversity was inversely related to patch size. Genetic diversity tended to be higher in intertidal areas that had smaller patch sizes and were more prone to disturbance.
- Ruckelshaus (1994) found that a distance of four meters around a plant was adequate to genetically separate individual plants.

Table 2. Summary table: Values of eelgrass metrics associated with ecological attributes from the review of literature.

Ecological attribute	Eelgrass metric	Value
Benthic Habitat	Minimum area of eelgrass presence that affects habitat value	1–2 m^2 (Fonseca *et al.*, 1998) 0.24 m^2 (Hirst & Attrill, 2008)
Sediment Stability	Minimum area of eelgrass to significantly reduce current velocity	0.3 m^2 (Fonseca & Koehl, 2006)
Seed Dispersal	Seed dispersal distance	5 m (Ruckelshaus, 1996)
Genetic Diversity	Distance at which plants can be genetically distinguished	4 m (Ruckelshaus, 1994)
Vegetative Reproduction	Mean rhizome growth rate	26 cm/yr (Marbà & Duarte, 1998; Sintes *et al.*, 2006)
Persistence	Minimum eelgrass density associated with persistence	> 32 shoots per patch area (Olesen & Sand-Jensen, 1994)

Ecological attribute	Eelgrass metric	Value
	Eelgrass cover associated with greater persistence	> 50% cover (Fonseca & Bell, 1998)

Summary of available data relevant to the definition of eelgrass edge

Existing eelgrass data available to the staff of Washington DNR were evaluated to see if any patterns in eelgrass density, patchiness, or persistence emerged, or if perhaps there was any indication that further investigation of these data might be useful in developing eelgrass bed criteria. The four data sources described below include the Dumas Bay SeagrassNet site, the Submerged Vegetation Monitoring Program density grab samples, mitigation monitoring data from a Maury Island site, and plant morphology data from the Washington DNR stressor project.

Dumas Bay SeagrassNet site

SeagrassNet is a worldwide ecological monitoring program that documents the status of seagrass resources. The program began in 2001 in the western Pacific and now includes 115 sites in 32 countries. It has a global monitoring protocol and web-based data reporting system. A SeagrassNet site was established in Dumas Bay in Washington's Puget Sound in May of 2008. SeagrassNet sampling protocol requires that three fixed transects be established in an area of seagrass presence that is representative of or typical for the area. The fixed transects run along the shore, parallel to the beach. Transect A is located approximately one meter into the contiguous eelgrass from the shoreward edge. Transect C is one meter into the contiguous eelgrass from the waterward edge. Transect B runs through the center of the contiguous eelgrass (Figure 1).

Contiguous is defined as any eelgrass shoot that is within one meter or less of another eelgrass shoot. Furthest shoot data were compiled and analyzed from the Dumas Bay SeagrassNet site. The furthest (last, terminal) shoot is measured from three points (0, 25, and 50 m) perpendicular from the shallow (transect A) shoreward and deep (transect C) seaward transects (Figure 1a). The distance to the edge of the area of contiguous eelgrass (where the space between shoots is equal to or less than one meter) is also measured from these points. Data is collected quarterly.

Figure 1. Illustrates SeagrassNet transect placement, measurement to bed edge, and furthest shoot distance.

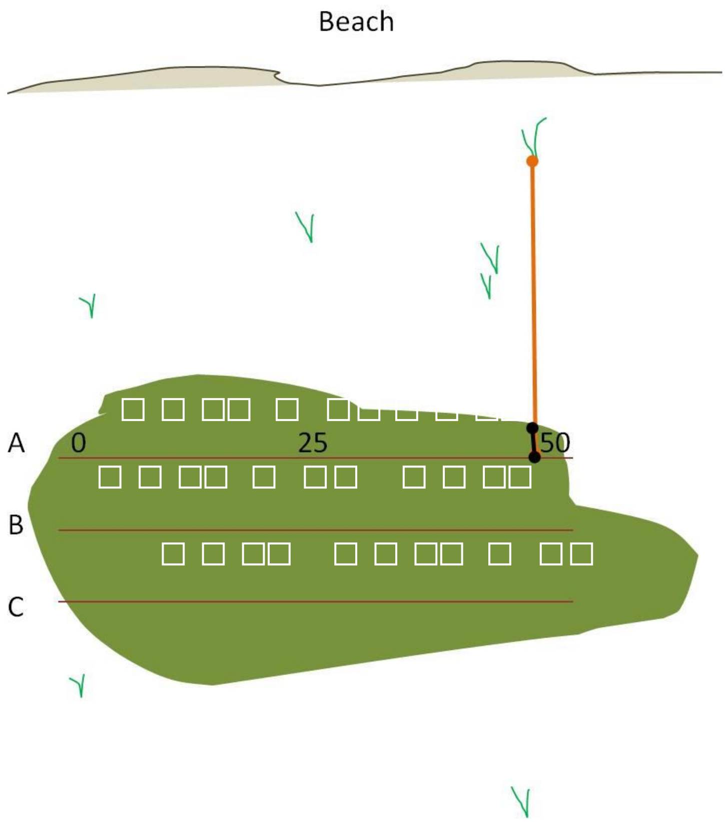
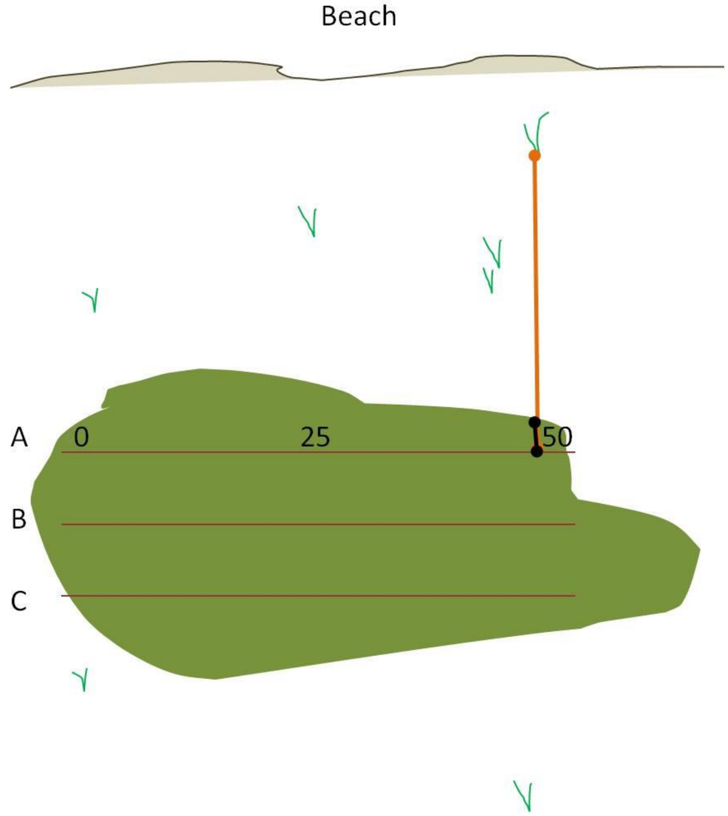


Figure 1a. Schematic of SeagrassNet site and distance to edge of bed (black line) and furthest shoot distance (orange line). (Diagram not to scale).



From May 2008 through January 2011, thirteen sampling events occurred. There were not enough sample times for the collection of furthest shoot data from the deep transect (transect C) to provide any meaningful information for the analysis. A basic evaluation of the furthest shoot data collected from the shallow transect (transect A) revealed the following:

Furthest shoot distance: Dumas Bay

Sparse, patchy eelgrass along the intertidal edge of larger contiguous eelgrass areas had been observed in the field by many of the workgroup participants. From the discussion, it seems that the size, distance from the contiguous eelgrass, and ephemeral nature of this eelgrass varies considerably. This prompted an examination of the available data to see whether any of these parameters might be quantified. Here, the furthest shoot refers to the single furthest shoot from the central area of the eelgrass.

- Furthest shoots were not present throughout the year; they were only present during the spring and summer sample times.
- When furthest shoots were present, they were located near the places they had been previously detected (the maximum change in furthest shoot distance was 5.3 m).
- The maximum distance of a furthest shoot from the contiguous edge was 8.9 m.
- The change in contiguous edge location over all sampling times (through all seasons) ranged from 0.4 m at the center position to 11.3 m at the left position.

- Net change from the first spring sampling (May 2008) to the most recent spring sampling (April 2010) was much smaller, ranging from 0.1 m at the center position to 1.7 m at the left position.

The results are summarized in Table 3 and Table 4.

Table 3. Furthest shoot distance, Dumas Bay, SeagrassNet site.

	Shallow transect furthest shoot distance (M)				n (# Times furthest shoots present)	n (# Times bed examined for furthest shoot)
	Max	Min	Mean	Std dev		
SeagrassNet Site, Dumas Bay May '08–Jan '11	8.9	1.8	6.6	2.3	7	34

Table 4. Change in edge and furthest shoot location, Dumas Bay, SeagrassNet site.

Position on Transect A	Max seasonal change in edge distance (m)	Max annual change in edge distance	Max change in furthest shoot distance (m)
Center	+0.4	+0.3	+1.5
Left	-11.3	-3.4	-1.7
Right	-6.1	+2.2	+5.3

This analysis provided some insight into the magnitude of changes in the edge and furthest shoot location, as well as the seasonality in the expansion and contraction of the edge and furthest shoot presence at this site. In addition, a pilot investigation of data from Washington DNR's Submerged Vegetation Monitoring Program was conducted to see what might be learned about furthest shoot distance from contiguous bed edge and what comparisons could be made among the different areas of Puget Sound. This preliminary analysis indicated that the furthest shoot distance could not be estimated using the Submerged Vegetation Monitoring Program's data. The program's data did not distinguish between a single blade in a square meter and thousands of shoots per meter. Further analysis of the data was therefore abandoned.

Eelgrass density: Dumas Bay

Eelgrass density and percent cover estimates were conducted at fixed random sites along three 50-m longshore transects at +1, 0, and -1.6 mean lower low water (MLLW) tidal elevations. Seasonal variability is apparent in density and percent cover, with maximum values observed in the spring and summer (data not shown). Interannual variability is also observed. This is apparent from the range in density and the standard errors reported only for the July samplings (the SeagrassNet site is sampled quarterly) of 2008–2011, as documented in Table 5.

Table 5. Shoot density and percent cover at Dumas Bay, SeagrassNet site.

Transect & Elevation (MLLW)	Date	Average Density (shoots/m^2)	SE (n)	Average % Cover	SE (n)
A, +1	July '08	597.3	277.7 (12)	28	12 (12)
A, +1	July '09	292.0	206.7 (12)	16	9 (12)
A, +1	July '10	184.0	97.9 (12)	12	6.8 (12)
A, +1	July '11	109.3	76.8 (12)	8	5 (12)
B, 0	July '08	769.6	175 (12)	46	6.6 (12)
B, 0	July '09	878.7	192.4 (12)	61	7.9 (12)
B, 0	July '10	892.0	135.6 (12)	72	9.7 (12)
B, 0	July '11	841.3	148 (12)	62	9.1 (12)
C, -1.6	July '08	210.7	32 (12)	46	6.2 (12)
C, -1.6	July '09	280.0	33 (12)	38	4.1 (12)
C, -1.6	July '10	186.7	29.6 (12)	28	4.9 (12)
C, -1.6	July '11	130.7	10.9 (12)	26	4.3 (12)

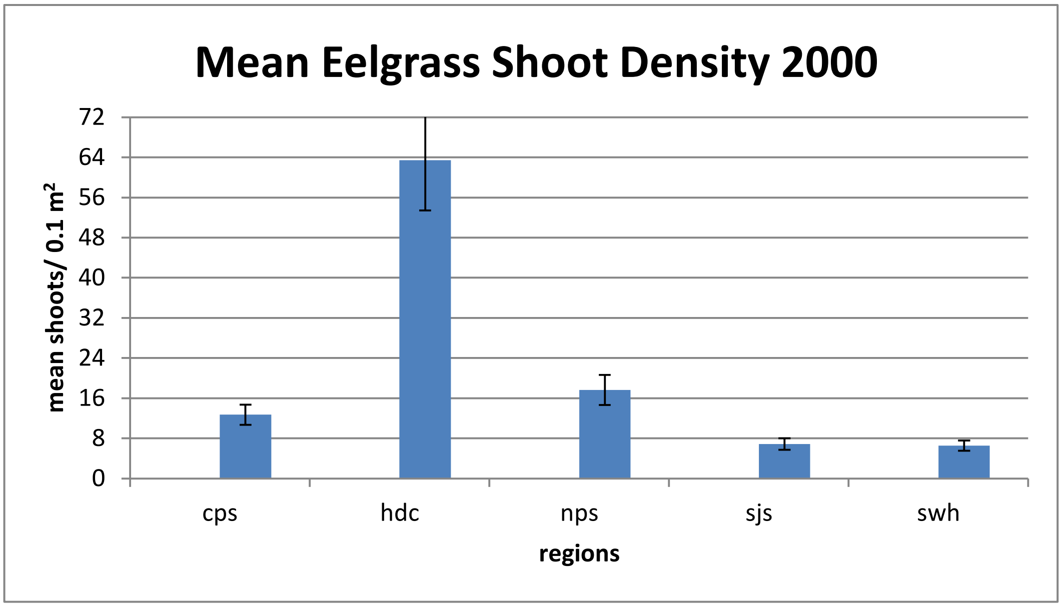
Submerged vegetation monitoring program: eelgrass shoot density

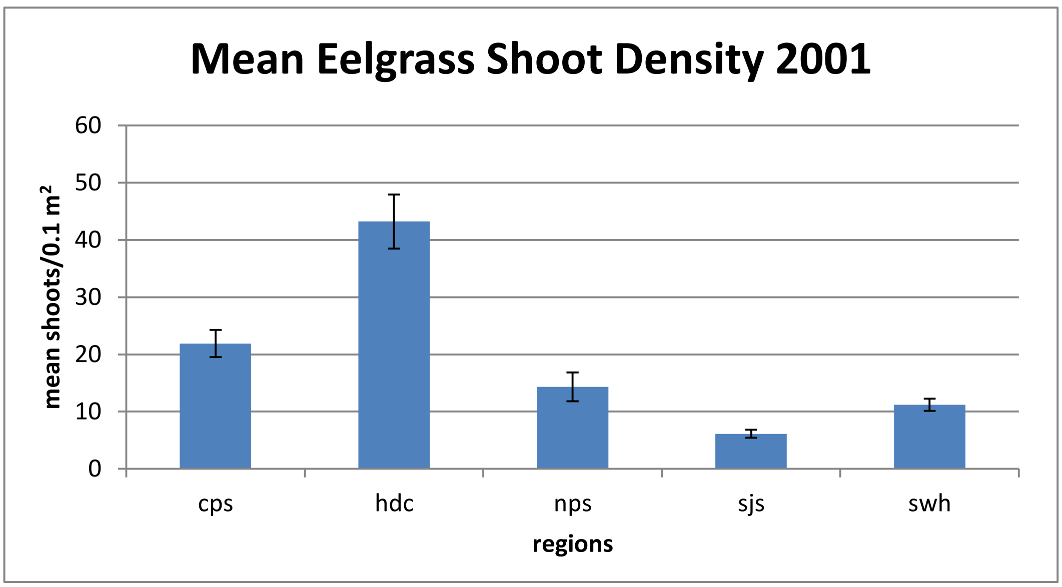
Environmental parameters influencing eelgrass plant structure and eelgrass density have been reported in scientific literature (Boese et al., 2003; Turner et al., 1999). Workgroup participants have also cited field observations of geographic differences in plant structure and density. This encouraged an examination of the available data on eelgrass shoot density, specifically to see if regional differences or variability in eelgrass density over time might be quantified.

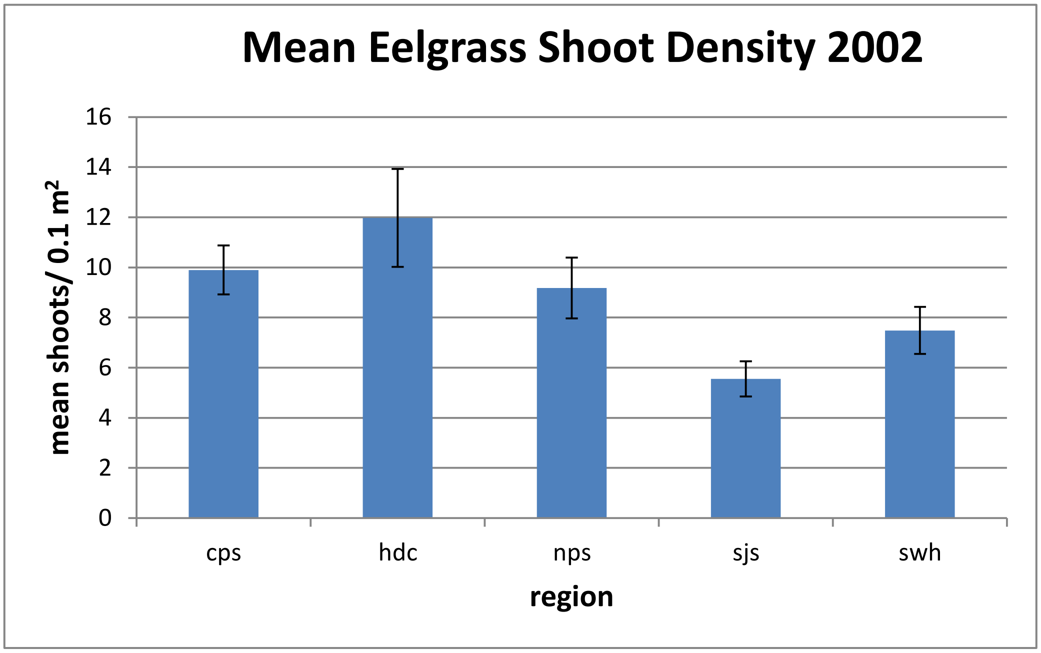
DNR grab sample density counts

Initial sampling for the Submerged Vegetation Monitoring Program included shoot density counts of grab samples collected with a van Veen sampler. An average of 23.9 shoots per sample, with a minimum of 1 shoot per unit area, was reported from 1,020 samples collected during 2000–2003. Sites sampled within each region were not necessarily sampled each year, although some sites were sampled in consecutive years. Sampling did not fall in the same period for each year either. While the absolute density numbers differed each year, visual observation of the data (see plots in Figure 2) does indicate a fairly consistent pattern of relative difference in shoot density among the five regions sampled, with Hood Canal (hdc) having the highest density, Central Puget Sound (cps) and North Puget Sound (nps) competing for second highest, and then South Whidbey (swh) and San Juan Island (sjs) with the lowest density.

Figure 2. Mean eelgrass shoot density from annual grab sampling by region, 2000–2002. Error bars are standard errors of the means.







Mitigation monitoring data: Maury Island

Eelgrass at a proposed project site on Maury Island was monitored intensely in 2005, 2008, and 2009 by the consulting firm Grette Associates LLC. Fixed grids with grid cell size of 1 x 1 m were established to encompass the entire eelgrass area. Dive survey sampling included eelgrass percent cover estimates within each square-meter grid cell, eelgrass density shoot counts within a 0.25 m^2 portion of each grid cell, and delineation of eelgrass presence in each square meter. Eelgrass survey maps from sample years 2005, 2008, and 2009 are reproduced in Figures 3–5 below, with eelgrass presence delineated and the density counts per 0.25 m^2 indicated within each grid cell. Sampling occurred during July for 2005 and 2008, and then in August for 2009. The images are from Northwest Aggregates: Maury Island Gravel Dock Annual Eelgrass Survey Reports, December 19, 2005, September 19, 2008, and December 15, 2009, prepared for Northwest Aggregates by Grette Associates LLC.

Eelgrass density: Maury Island

Close examination of the data from eelgrass monitoring of the north, south, and control patches (Figures 3–5) indicated differences in the stability of the three eelgrass areas. These findings are summarized in Table 6.

Table 6. Eelgrass area and mean density at Maury Island gravel site.

Patch Name	**Year**	**Area (m^2)**	*Net Change in Area (m^2) from '05 to '09*	**Average Density (shoots/m^2)**	*Net Change in Avg. Density (shoots/0.25m^2) from '05 to '09*
North	2005	126		77	
	2008	127		72	
	2009	85	-41	13	-64
South	2005	148		54	
	2008	152		56	
	2009	218	+70	28	-26
Control	2005	261		30	
	2008	256		37	
	2009	265	+4	26	-4

Figure 3. Eelgrass monitoring, Maury Island, north patch, 2005, 2008, 2009 (Grette Associates, 2005, 2008, 2009).

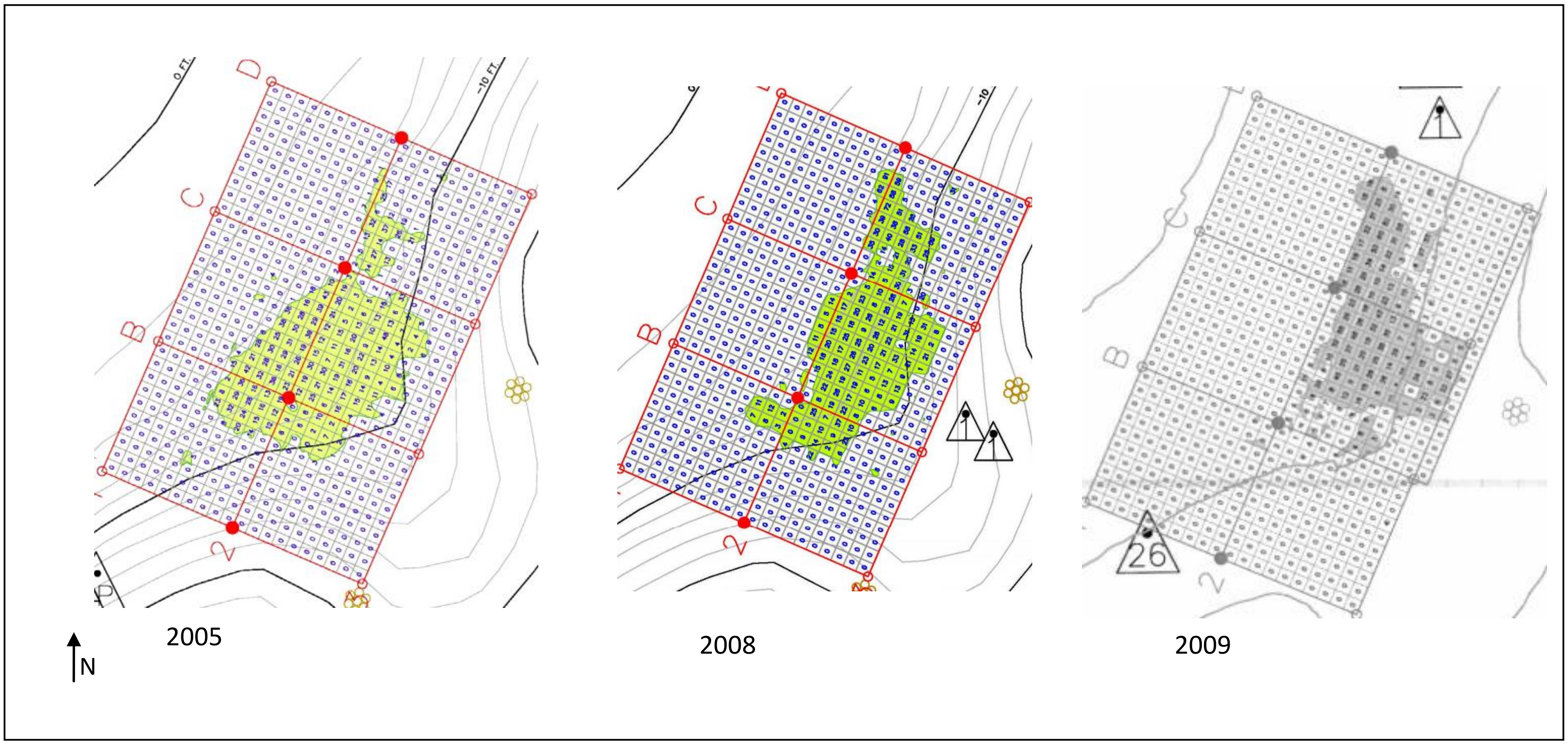
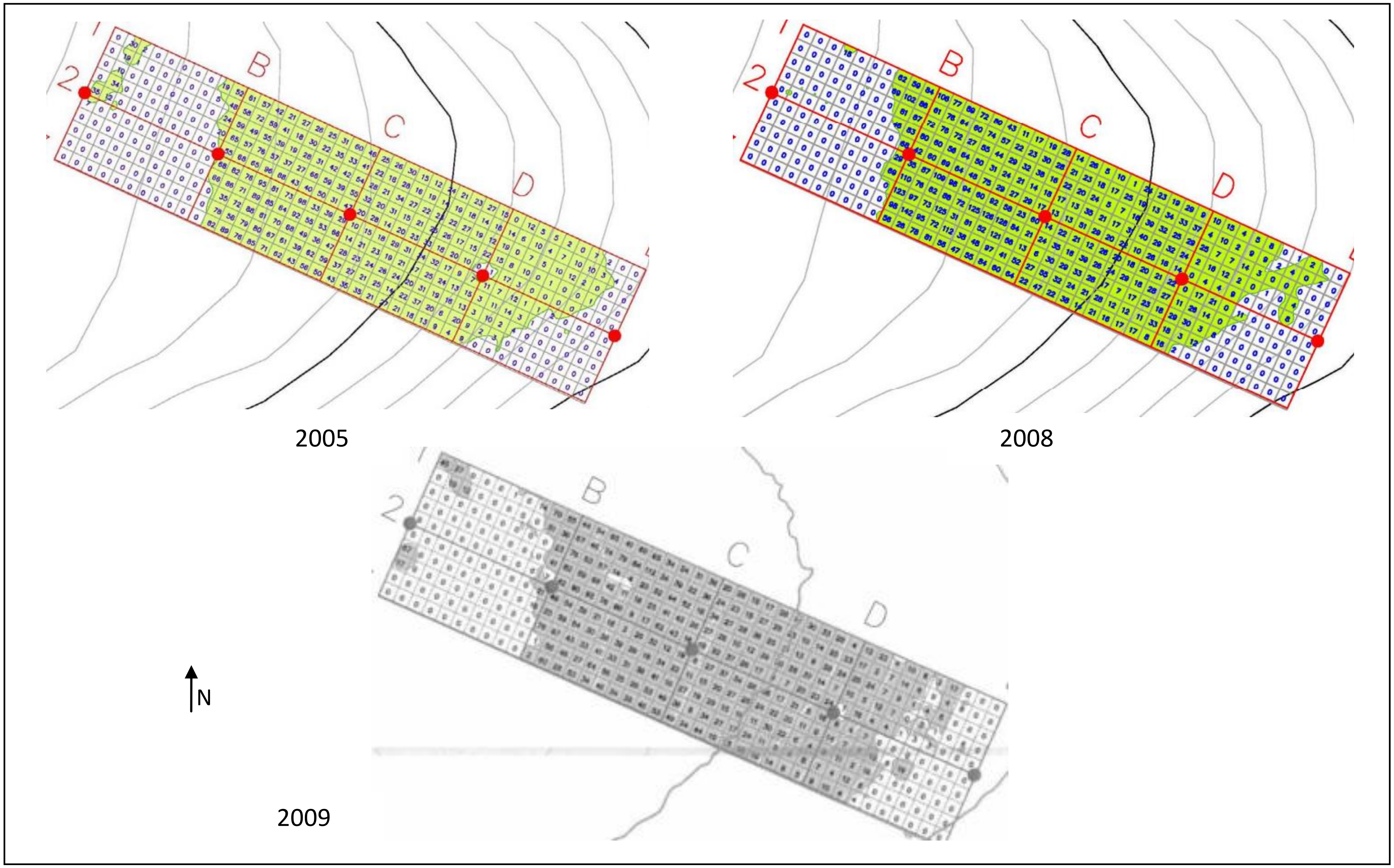


Figure 4. Eelgrass monitoring, Maury Island, south patch, 2005, 2008, and 2009 (Grette Associates, 2005, 2008, 2009).

Figure 5. Eelgrass Monitoring, Maury Island, Control Patch, 2005, 2008, and 2009 (Grette Associates, 2005, 2008, 2009)



The apparent differences in contiguous eelgrass stability that the comparison of the control site to the other two eelgrass areas revealed may be an artifact of differences between the survey limits of the control site and those of the north and south sites: The control site survey was limited to a swath from a larger contiguous area, while the survey extents of the north and south sites contained the entire eelgrass presence in each case, and surveys increased if necessary to capture edge migration. Assessment of the comparison between the north and south sites and relative change for each of these two areas over time is not affected by this survey limitation.

The eelgrass area and average shoot density remained relatively stable at the control site (again, this may be an artifact of the extent of the survey for this site). The eelgrass area increased in the south site and decreased in the north site, while the average shoot density decreased in both north and south patches.

The eelgrass edge of the north site moved approximately two meters east between 2005 and 2008 (spreading out both north and south). The northward edge contracted approximately five meters from 2008 through 2009.

The western eelgrass edge of the south site migrated approximately two meters to the east (filling in the patchier northern portion) from 2005 to 2008. It continued to migrate approximately four more meters eastward between 2008 and 2009.

Migration of the control site edges cannot be accurately assessed, because the monitoring area does not contain the long-shore edges of that eelgrass area. It is apparent that smaller areas of eelgrass along the shoreward edge were ephemeral in size and shape.

Furthest shoot: Maury Island

When looking at the pattern of density in all sites for three years, gradual tapering off of the density toward the shallow edge is never observed. In fact, some of the highest density grid cells are located directly on the shallow edge. The decrease in density is slightly more gradual on the deeper edge, but only one to two meters before complete drop-off.

In the north, south, and control sites, furthest shoots were documented (shoots located beyond a meter distance of the contiguous eelgrass area) off the shallow and deep edges. A furthest shoot was not always present. When present, furthest shoot distances on the shoreward edges ranged from 1.1 m to 8.0 m. The furthest shoot distances on the seaward edges (when present) ranged from 2.1 m to 3.5 m. Table 7 summarizes the furthest shoot distances measured at these sites.

While eelgrass presence did not migrate beyond the location at which a furthest shoot was found (shoreward or seaward), eelgrass did migrate along shore to areas where no eelgrass had been found during the previous sample time.

Table 7. Edge migration and shoot distance in eelgrass patches at Maury Island gravel site.

Patch Name	Year Sampled	Edge Migration: Expansion, +, Contraction, -(m)	Shoreward Furthest Shoot Distance (m)	Seaward Furthest Shoot Distance (m)
North Patch	2005		1.7	_
	2008	+2 east	2.0	2.1
	2009	-5 north		
South Patch	2005		1.1	3.5
	2008	+ 2 east	_	_
	2009	+4 east		
Control Patch	2005		_	_
	2008		8.0	_
	2009		_	_

Eelgrass persistence: Maury Island

Persistence of eelgrass area and density was evaluated in the Maury Island data (Table 8) so that it could be compared with the estimates provided in the literature. Only eelgrass presence that had a maximum area of 2 x 2 m was included in the analysis. Eelgrass that persisted beyond a season was larger in area and had a higher average shoot density compared to eelgrass that did not persist. The area of eelgrass that persisted was at least 0.3 m^2, with minimum density of 3 shoots per 0.25m^2.

Table 8. Minimum area and shoot density for eelgrass persistence at Maury Island gravel site.

Patch Persistence	Shoot Density (shoots/0.25m^2)				Patch Area (m^2)			*n*
	average	*min*	*max*	*SE(n)*	*average*	*min*	*max*	
> 1 season	54.4	***3***	124	2.44	0.9	***0.3***	4.0	*10*
< 1 season	13.7	1	36	0.76	0.6	0.1	1.0	*14*

Plant morphology data: Washington DNR Eelgrass Stressor Project

Plant structure provides important ecological functions. Above-ground shoots can provide three-dimensional structure for fish refugia and for epiphyte and invertebrate attachment. Below-ground structure provides habitat for macroinvertebrate attachment and sediment stabilization. Morphology of the above- and below-ground structure of *Z. marina* differs with environmental factors, as has been documented (Turner et al., 1999; Frederiksen et al., 2004). Plant structure is relevant to the development of bed criteria, because the distance between the plants and the bed edge is influenced by the length of shoots and rhizomes. The results of the analysis of plant morphology data from Washington DNR's eelgrass stressor project are presented below (Table 9).

The average shoot length at four sites (SE = 1.4, n = 180) in Puget Sound was 53.1 cm, with an average maximum shoot length of 89.7 cm (SE = 6.5, n = 45)(Washington DNR unpublished data). Average rhizome length at these sites was 33.3 cm (SE = 2.9, n = 169), with an average maximum rhizome length of 68.4 cm (SE = 4.4, n = 43).

Table 9. Eelgrass morphology metrics.

Ecological Attribute	Eelgrass Metric	Value
Eelgrass Morphology	Shoot length	Average shoot lengths ranged from 53.1 cm to 89.7 cm (Washington DNR unpublished data)
	Rhizome length	Average rhizome length ranged from 33.3 cm to 68.4 cm (Washington DNR unpublished data)

Index of eelgrass densities in Puget Sound and Willapa Bay

Eelgrass densities measured throughout Puget Sound and Willapa Bay are presented in Table 10. In the workshops, it was suggested that when pre-construction eelgrass surveys are conducted for proposed projects, it may be possible to begin developing a spatially explicit index of patch densities for comparison. A preliminary compilation of eelgrass density data is presented in Table 10; the sample size and standard error are indicated when known. These data were largely drawn from scientific publications, but other sources include Washington DNR Aquatics program field surveys, and environmental evaluation reports required for proposed projects on state-owned aquatic lands. These data may be helpful to those who are developing mitigation performance standards and selecting reference sites. These data cannot be used to determine minimum patch size, because they are reported as means (most often with very large variation in the mean) or ranges of densities, with limited or no information on sample size.

Table 10. Compilation of eelgrass densities measured throughout Washington.

Location (elevation)	Date	Average or Range of Densities (shoots/m^2)	SE	n	Reference
Puget Sound					
Lummi Bay	Apr-May 2007	160.7		20	Yang (2011)
North Samish Bay	Apr-May 2007	157		20	Yang (2011)
South Samish Bay	Apr-May 2007	177.1		20	Yang (2011)
Padilla Bay	Apr-May 2007	207.8		20	Yang (2011)
Similk Bay	Apr-May 2007	78		20	Yang (2011)
Kayak Point	Apr-May 2007	50.7		20	Yang (2011)
North Hood Canal	Apr-May 2007	137.8		20	Yang (2011)
Dabob Bay, Hood Canal	Apr-May 2007	155.9		20	Yang (2011)
Edmonds	Apr-May 2007	89.1		20	Yang (2011)
Carkeek Park	Apr-May 2007	212.2		20	Yang (2011)
Golden Gardens	Apr-May 2007	156.4		20	Yang (2011)
Seabeck, Hood Canal	Apr-May 2007	277.1		20	Yang (2011)
Lynch Cove, Hood Canal	Apr-May 2007	76.2		20	Yang (2011)
Purdy Spit, Car Inlet	Apr-May 2007	260		20	Yang (2011)
Rocky Point, Case Inlet	Apr-07	150		20	Yang (2011)
	May-07	89		20	Yang (2011)
Union, Hood Canal	Apr-May 2007	81.5		20	Yang (2011)
Dumas Bay	Apr-May 2007	141.8		20	Yang (2011)

Location (elevation)	Date	Average or Range of Densities (shoots/m^2)	SE	n	Reference
Dumas Bay: Washington DNR SeagrassNet Site (-1.6 to +1 MLLW)	Apr-08	464.9	77.5	36	Washington DNR unpublished data
	Jul-08	525.9	87.6	36	DNR unpublished data
	Apr-09	479.5	79.9	36	DNR unpublished data
	Jul-09	483.6	80.6	36	DNR unpublished data
	Apr-10	352.4	58.7	36	DNR unpublished data
	Jul-10	420.9	70.2	36	DNR unpublished data
	Apr-11	392.2	66.4	36	DNR unpublished data
	Jul-11	360.4	60.1	36	DNR unpublished data
Post Point Outfall, Bellingham	2005	22–61			City of Bellingham (2005)
Golden Tides, Bellingham	Jun-06	28–39			Geomatrix (2007)
	Jul-08	29–88			Geomatrix (2008)
Taylor Ave. Dock, Bellingham	Jul-98	42–238		30	Talyor Assoc. (1998)
	2004	49–235			Anchor Env. (2004)
Shannon Pt., Bellingham	2009	5–50			ATSI (2010)

Location (elevation)	Date	Average or Range of Densities (shoots/m^2)	SE	n	Reference
Maury Island Gravel Site (North)	Jul-05	77			Grette Assoc. (2005)
	Jul-08	72			Grette Assoc (2008)
	Aug-09	13			Grette Assoc (2009)
Maury Island Gravel Site (South)	Jul-05	54			Grette Assoc. (2005)
	Jul-08	56			Grette Assoc (2008)
	Aug-09	28			Grette Assoc (2009)
Maury Island Gravel Site (Control)	Jul-05	30			Grette Assoc. (2005)
	Jul-08	37			Grette Assoc (2008)
	Aug-09	26			Grette Assoc (2009)
Willapa Bay					
Oysterville	Apr-May 2007	114.4		20	Yang (2011)
Oysterville (-0.5 to +1.5 MLLW)	Jul-07	290	14	20	Ruesink *et al.* (2010)
Stackpole (-0.5 to +1.5 MLLW)	Jul-07	353	39	20	Ruesink *et al.* (2010)
Stackpole Flats	2007	22.8	5.3	44	Ruesink *et al.* (2010)
Nahcotta (-0.5 to +1.5 MLLW)	Jul-07	69	7	20	Ruesink *et al.* (2010)
Parcel A., Willapa Bay	Apr-May 2007	100.3		20	Yang (2011)
Willapa Bay (7 Locations)	Jul-04	159.5	33.9	7	Ruesink *et al.* (2006)

Summary of relevant findings

- Changes in ecological function were observed where a very small area of eelgrass was present; differences in benthic community diversity were observed when a 0.24 m^2 sized area of eelgrass-vegetated substrate was compared to an unvegetated substrate. An eelgrass area of 0.3m^2 was documented to have increased sediment trapping function when compared with unvegetated bottom.
- A minimum density of 3 shoots per 0.25 m^2 was necessary for an area of eelgrass to persist from one season to the next at a site in Puget Sound.
- With reported rhizome growth of 0.3 m per year and observed average rhizome lengths ranging from 0.3 to 0.7 m, a distance of 1 m would be necessary to ensure that the below-ground biomass of two adjacent shoots are captured when delineating a bed.
- Eelgrass edges at a site in Puget Sound were documented to migrate seasonally and annually. Maximum annual expansion to areas beyond the previously recorded edge was documented at 4 meters, while maximum annual contraction to areas of the previously recorded bed interior was up to 5 meters.
- Edge migration shoreward or seaward was always within the distance defined by the furthest shoot; however, edges also migrate along the shore, where the furthest shoot is not defined.
- Shoots greater than 1 meter from a contiguous eelgrass area have been documented appearing and disappearing seasonally and interannually.

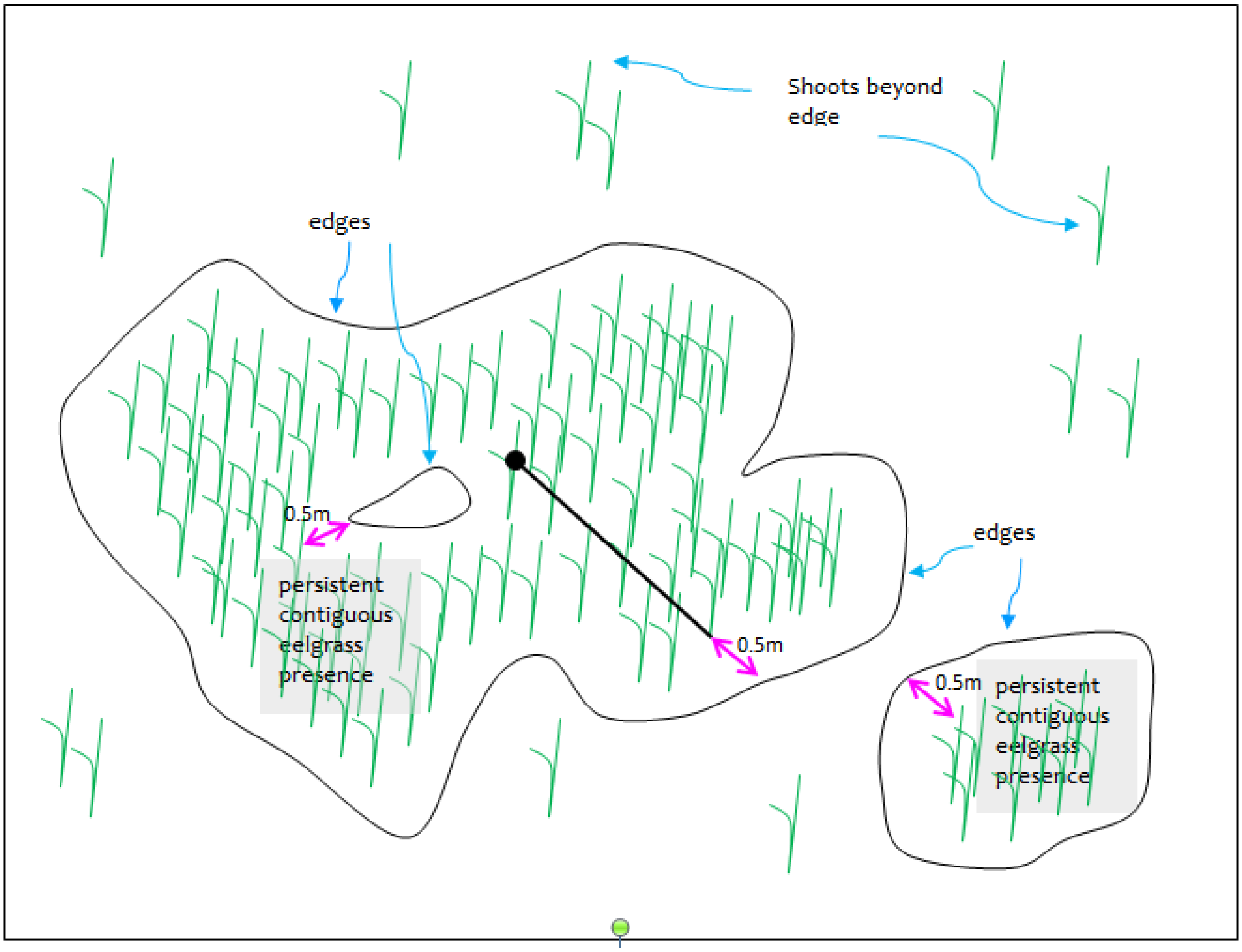
Proposed criteria

The proposed criteria for identifying the minimum eelgrass presence needed to delineate a vegetated edge with demonstrated ecological function are listed in Table 11. The criteria are based on information derived from review of the scientific literature and examination of available field data (from Puget Sound sites). Note that these criteria emerged from the limited data and information available regarding ecological function of *Zostera marina* characteristics and dynamics and are meant to provide an operational definition. Future sampling and further analysis may indicate that an adaptation or refinement of these criteria is necessary. In particular, field data from the estuaries of Washington’s outer coast may provide scientific support for establishing separate criteria for those estuaries.

Table 11. Criteria for eelgrass bed edge and beyond.

Terms	Criteria	Bed edge or beyond?	Rationale
Persistent Bed Edge	Begin at a point within the interior of the bed (where ≥ 3 shoots/0.25m^2 within 1 m of adjacent shoots); move along any radial transect. Find the last shoot that is within 1 m of an adjacent shoot along that transect. Continue 0.5 m beyond this shoot: This is the bed edge. Both exterior and interior edges of bed can exist (Figure 6).	Bed edge	• Vegetated areas as small as 0.24 m^2 demonstrated different ecological function from unvegetated substrate. • 3 shoots per 0.25 was the minimum density necessary for an eelgrass patch to persist from one season to the next in Puget Sound. • Observed average rhizome lengths ranged from 0.3 to 0.7 m, and rhizome growth rates of approximately 0.3 m per year have been documented. Observed average shoot lengths ranged from 0.5 to 0.9 m. • Two adjacent shoots would require a minimum distance of 1.0 m to accommodate above- and below-ground parts of the plant. • A distance of 0.5 m beyond the last shoot is needed to accommodate the below-ground rhizome of an edge shoot.
Shoots or Patches	Single shoot or patches < 3 shoots/0.25m that are > 1 m from adjacent shoot	Beyond	• The ecological function of patches below this size and density has not been documented. • Patches below this size and density have been documented as ephemeral.
Ephemeral Shoots and Patches	Shoots or patches that may disappear then reappear from one season or year to the next	Beyond	• The ecological function of shoots and patches with limited temporal consistency has not been documented. • Ephemeral shoots and patches cannot feasibly be monitored for before-after effects analysis.

Figure 6. Schematic depicting two distinct, intact, contiguous eelgrass areas. Edges are 0.5 m beyond the last shoot found within 1 m of an adjacent shoot.



Conservation approaches

The ephemeral nature of eelgrass, particularly the edges of eelgrass presence, has been documented in the scientific literature and by data from Puget Sound and Willapa Bay. It has also been anecdotally observed in the field by shellfish growers and scientists. SeagrassNet protocol acknowledges it by requiring measurement from a fixed transect to the edge and to the furthest shoot. Eelgrass at the edge is less persistent than eelgrass near the center of a contiguous area. This migratory characteristic of eelgrass makes it a challenge to specify protocols for detecting changes effected by a specific activity. It is also a problem for those making management decisions, such as at what distances from the eelgrass it might be appropriate to encourage use and access of the tidelands, while still protecting sustainable eelgrass functions. Table 12 presents some metrics from published literature and the recent data analysis that may be relevant in determining these distances.

Table 12. Metrics relevant for developing buffers.

Relevant ecological attribute	Eelgrass Metric	Value
Potential Migration Zone	Expansion (+) or contraction (-) distance	Maximum documented annual bed expansion of +4 m, and contraction of -5 m (Washington DNR un-published data for two different sites) sampled over 4 year period).
Seed Dispersal	Seed dispersal distance	5 m (Ruckelshaus, 1996)
Genetic Diversity	Distance at which plants can be genetically distinguished	4 m (Ruckelshaus, 1994)

Recommendations

The revised goal described in the introduction of this memo was to determine the criteria for defining an eelgrass bed edge. The definition ". . . must allow for repeatable delineation of the beds, so that any impacts from activities authorized by Washington DNR in marine tidelands can be avoided or minimized with the application of appropriate conservation measures." There was consensus early on among the workshop participants that the purpose of this effort was to apply scientific evidence to distinguish between an intact, persistent, and functioning eelgrass area and spare individual blades of eelgrass, ephemeral eelgrass areas, or potential eelgrass habitat. A comprehensive review of scientific literature and analysis of available data led to the following recommendations:

- Apply the proposed criteria listed in Table 11 to delineate an edge around eelgrass presence. This distinguishes between contiguous eelgrass presence and sparse shoots of eelgrass that may be present at a site, but are not within a contiguous area.

- Consider the values provided in Table 12 as the uncertainty distance around an intact, persistent eelgrass area. It is only through siting activities within this expansion, contraction, and seed dispersal distance that positive or negative changes to eelgrass can be effectively monitored for adaptive management.

Next steps

It was suggested that further examination of the available data might be used to develop some indices of bed characteristics from different areas of the state. Various seagrass attributes (such as shoot density, plant architecture, and colonization rates) have been shown to have a strong relationship to the physical setting of an area (Frederiksen et al., 2004; Robbins & Bell, 1994; Turner et al., 1999). Monitoring interannual variability in shoot density and the edge location in different areas would provide information on how to determine best site uses that do not conflict with sustainable ecological function of eelgrass habitat.

If the intent is to develop the most effective operational definition possible, it will be useful to design initial baseline and adaptive management sampling to evaluate the practicability of the bed criteria and some of the eelgrass metrics listed in Table 2. Data relevant to longshore dynamics of *Zostera marina* are limited (Frederiksen et al., 2004); therefore, Washington DNR's adaptive management monitoring should include baseline sampling designed to explore interannual edge migration in both the cross and longshore.

These proposed edge criteria, delineation methods, and conservation approaches are the outcome of a series of technical workgroup discussions. This information can serve as a starting point for future policy deliberations on developing effective conservation measures that will allow for management of resources, while encouraging sustainable uses on state-owned aquatic lands.

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Anthropogenic Noise Impacts on Spawning and Ecology of Atlantic Fisheries: Implications for Managers and Long-Term Fishery Productivity.

REVISED BY R. GRANT GILMORE, JR., PH.D.

~~**I added in some of the text we sent to Grant in orange. So some of the information might be redundant and need to be combined, but I wanted to see what you wanted to leave in vs. remove**~~

Grant's text is VERY scientific and does not follow the outline in regards to length of different sections. This should be remedied but I wanted you to see what you think we should keep/remove

****The Habitat Committee wants to use superscript numbers for the references, instead of listing the names and dates in the text, similar to a Science publication, to make it easier to read. I will do this at the end once we have the text finalized****

*****The Habitat Committee would like to include a figure displaying the distance different sounds travel in the ocean (e.g. freighter vs. whale call vs. air gun vs. SCUBA diver). If you know of one, please add it in*****

******We plan to add links to recordings of different sounds, which I will do once the text is finalized******

*******I have not checked the citations yet – some are probably missing and some might be duplicates. I'll do that at the end*******

I. Introduction

The oceans are full of both natural and anthropogenic sounds. The importance of auditory stimuli is amplified in aquatic environments due to differences in the way sound, light, and chemicals behave underwater. Because water is denser and more viscous than air, the propagation of light and the diffusion of chemicals are both severely inhibited. In contrast, sound can move over four times faster and travel farther with less degradation underwater than it can through the air (Rogers and Cox 1988; Ward 2015). Thus sound, not light nor chemical cues, is the most important sensory system for many aquatic organisms, including most fishes (Tavolga 1960, 1980; Richardson et al, 1995; Stocker 2002; Au and Hastings 2008; Staaterman et al. 2013, 2014).

Commented [WL1]: I think that Grant's text here is important and should remain. Guess you could make it a bit more lay-reader-friendly, but the current language is okay by me.

Unfortunately, many human activities occurring in coastal and marine habitats add noise to the natural soundscape, and these noises affect aquatic organisms and their interactions with one another. For example, as rates of sound production correlate to rates of spawning and reproductive success, any disruptions to the effective communication within fish and invertebrate species has the potential to reduce reproductive output and recruitment. The purpose of this report is to summarize our current understanding of the acoustic environment experienced by fishes, the human impacts on the marine soundscape, and how that impacts fish habitat and fisheries. While there is vast literature on the production and use of sound by marine mammals, including the effects of human-generated sound on these species, this is beyond the scope of this report, given ASMFC's fisheries management focus.

Commented [WL2]: While I'm okay with saying it is beyond the scope of this report, at some point I hope that we note that some marine mammals (Bottlenose Dolphin comes to mind)) prey on fishes and use sound to hunt them, which is why their prey (American Shad for one) have such sophisticated abilities to detect sound underwater.

II. The natural acoustic landscape and its importance to fishes

Aquatic environments, especially the oceans, are filled with abiotic sounds including tectonic activity, sea surface agitation, and sea ice activity. These sounds range from <10 Hz to >150,000 Hz with varying intensities and intermittency. Ocean waves and seismic activity produce constant low frequency noises of a moderate intensity, while dramatic seismic events, such as earthquakes or volcanic eruptions, produce relatively short bursts of very loud sounds. Weather, such as precipitation or high wind speeds, contributes to surface agitation causing increased abundance of 100-10,000 Hz noise (Martin et al 2014; Nowacek 2007; Peng 2015). Most abiotic, natural sounds are caused by surface agitation such as bubbles or spray impacting the water's surface. Weather conditions contribute to agitation, causing increased abundance of 100-10,000 Hz noise from precipitation or high wind speeds for the duration of the event (Martin et al. 2014; Nowacek 2007; Peng 2015).

Underwater noise is also generated by biotic sources, such as sound unintentionally produced as organisms move, forage, and release gas (Paxton et al. 2017). In addition to unintended noise, marine organisms make a variety of pointed sounds or calls to perform myriad biological and behavioral functions across different species (Peng 2015). Field and laboratory studies of fish physiology and behavior indicate that sound is a preferred sensory mechanism to detect predators or prey, find suitable habitat, orient, migrate, communicate, attract mates, and coordinate spawning (Putland et al. 2018 Journal of Fish Biology, Ecology of fish hearing). Not only do many species use sound to locate reproductive partners or indicate reproductive intent (Bass et al. 1997; Maruska and Mensinger 2009; Lamml and Krammer 2005, Montie et al. 2017), but some species, like the Pacific marine toadfish *Porichthys notatus*, become more sensitive to particular frequencies or their counterpart's sounds during periods of reproductive availability (Sisneros 2009; Maruska et al. 2012). Rates of sound production correlate to rates of spawning and reproductive success. Territorial species use agonistic calls to delineate an individual's territory and intimidate or deter competitors or predators (Ladich 1997; Vester et al. 2004; Maruska and Mensinger 2009**)**. Other uses of sound include navigation and orientation in the marine landscape, especially for planktonic larval stages of fishes and invertebrates (Radford et al. 2011; Vermeij et al. 2010), for the avoidance of predation (Remage-Healey et al. 2006; Hughes et al. 2014), and for communication (Buscaino et al. 2012; Janik 2014; van Oosterom 2016), and for locating suitable habitats for settlement (Simpson et al. 2004).

Commented [WL3]: We should define "agonistic."

Commented [LH4R3]: the complex of aggression, threat, appeasement, and avoidance behaviors that occurs during encounters between members of the same species. – Encyclopedia of Stress 2nd edition 2007.

III. Sources of anthropogenic noise in the oceans

Noise (unwanted sound) generated from human activities covers the full frequency of sound energies used by marine fishes. Anthropogenic sources of ocean noise are acute (episodic) and chronic (ongoing or continuous). Both types may occur within estuaries, on the continental shelf, or in open-ocean regions. Acute sources include pile driving, dredging, cable laying, bridge removal, and seismic surveys. Chronic sources include commercial and recreational boating, shipping activities, and wind turbine generators.

Watercraft of all kind produce very loud undersea noise, and are the most common sources of anthropogenic sound in coastal waters (Stocker 2002). These sounds can be amplified by complex reflected paths, scattering and reverberating because of the geography and geology of the submerged shoreline and bottom. Watercraft generate sound primarily from propeller action, propulsion machinery, generators, and water flow over the hull (Hildebrand 2005). Combined, these sounds generated from a large container vessel can exceed 190 dB at the source (Jasny 1999; see the case study below). Metropolitan areas and ports contain a diverse array of watercraft which constitute the dominant human derived soundscape: commercial and private fishing boats, recreational watercraft, coastal industrial vessels, public transport ferries, military craft, personal watercraft, and many others. Significant underwater sound production can also be generated from bridge automobile traffic, particularly during peak traffic periods.

Other inshore industrial and construction activities contribute to the aquatic soundscape. Underwater blasting with explosives is typically used for dredging new navigation channels in rocky substrates; decommissioning and removing bridge structures and dams; and construction of new in-water structures such as gas and oil pipelines, bridges, dams, and wind turbines. The potential for injury and death to fish from underwater explosives has been well-documented (Hubbs and Rechnitzer 1952; Teleki and Chamberlain 1978; Linton et al. 1985; Keevin et al. 1999). Pile driving activities, which typically occur at frequencies below 1000 Hz, have also led to fish kills (Hastings and Popper 2005). Intensity levels of pile driving have been measured up to 193 dB in certain studies (Hastings and Popper 2005).

Sub-bottom profilers are a type of shallow penetration (2–20 m), high-resolution seismic system that may be used in conjunction with deep penetration systems, which operates at a wide range of frequencies (400 – 24,000 Hz) and produces varying levels of peak sound (212-250 dB; Mooney et al. 2020). The loudest anthropogenic noises are generated by marine extraction industries such as oil drilling and mineral mining (Stocker 2002). The most common source of sounds is from air guns used to create and read seismic disturbances (Popper and Hastings 2009; Popper et al. 2005, 2014; NOAA 2016; Popper and Hawkins 2016). Air guns are used to generate and direct huge impact noises into the ocean substrate. The sound pressure wave created aids in reflection profiling of underlying substrates for oil and gas. Peak source sound levels typically are 250-255 dB. Following the exploration stage; drilling,

Commented [MT5]: Sub-bottom profiler is a category of sound producing device not previously mentioned, is commonly used, and has been brought to attention by ASMFC Board member (and Monty Hawkins).

Commented [MT6]: Should include some information on sound frequency and depth of signal penetration for comparison with sub-bottom profiler.

coring, and dredging are performed during extraction. Each of these activities also generates loud noises.

Sonar systems are used for a wide variety of civilian and military operations. Active sonar systems send sound energy into the water column. Sonar systems can be classified into low (<1,000 Hz), mid (1,000 – 20,000 Hz), and high frequency (>20,000 Hz). High frequency sonar telemetry is associated with vessel positioning, locating, steering, and remotely operated vessel control to support resource extraction operations (Stocker 2002). Most vessels have sonar systems for navigation, depth sounding, and "fish finding." Some commercial fishing boats also deploy various acoustic deterrent devices (pingers) to keep dolphins, seals, and turtles from running afoul of the nets (Stocker 2002). There is little information on the effects of acoustic deterrent devices on fish, however.

IV. Hearing in fishes and effects of anthropogenic noise

To understand whether and how these noises are likely to impact fishes, we need to understand their sensitivity to sound. This varies by species and among larval, juvenile, and adult stages (Wright et al. 2010). Many species have the same hearing frequency sensitivity that humans do (10 to 20,000 Hz; Tavolga 1960, 1980; Fine et al 1977; Fay et al. 2008; Popper and Hastings 2009; Popper and Fay 2011), and most fish produce sounds below 200,000 Hz (Tavolga 1960, 1980; Fine et al 1977; Fay et al. 2008). Sound frequencies below 100,000 Hz scatter and dissipate least, travel farthest underwater (Wenz 1962; Au and Hastings 2008; Ward 2015), and are the frequencies fish typically use for communication (Bass et al. 1997; Au and Hastings 2008; Popper and Fay 2011). Certain groups of fish, such as the herrings, sardines, and menhaden (clupeids), can detect ultrasound frequencies above 100,000 Hz (Fine et al. 1977b; Nestler et al 1992; Mann et al. 1997, 2001; Narins et al. 2013).

Sound energy is transmitted through both sound pressure and water particle motion. Although there is growing evidence that fish and invertebrates are sensitive to the particle motion caused by underwater noise (Casper and Popper 2010; Mooney et al. 2010; Mueller-Blenkle et al. 2010; Nedelec et al. 2016; Hawkins and Popper 2017; Sole et al. 2017; Popper and Hawkins 2018), it is technically challenging to measure. This has led to poor assessments of the impacts of particle motion on fish and invertebrates (Popper and Hawkins 2018). There is more information and research on effects of sound pressure in bony fishes and to a lesser extent invertebrates.

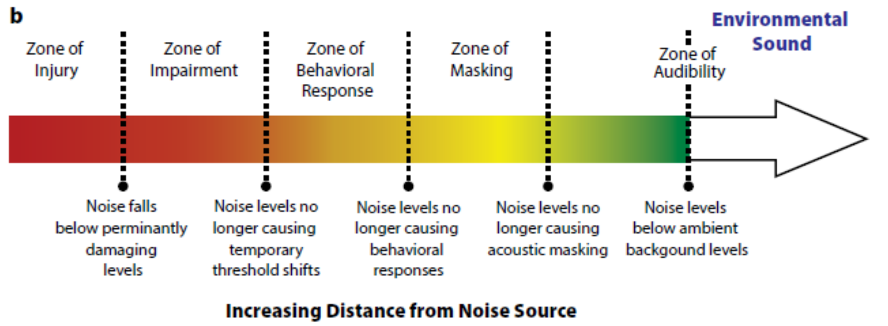
Fishes as a group have very complex and diverse interaction with sound and how they perceive it; however, relatively little direct research has been conducted on the impacts of noise to marine fish behavior, physiology, and life history. Some studies and formal observations have been conducted that identify general categories of noise impacts to fish: (1) physiological; (2) acoustic; (3) behavioral; and (4) cumulative. Add NOAA 2008 Tech memo "ocean noise" reference.

Commented [MT7]: Is most of the remaining text based on sound pressure since particle motion is poorly studied?

Commented [MT8]: Not sure I agree with this statement or am I missing some nuance. What is meant by "direct research"? The insinuation of minimal research runs counter to the extensive amount of literature cited (plus many more articles not referenced).

Commented [MT9]: Is there a place for this information:
Elasmobranch species that are more active swimmers appear to be more sensitive to sound than more sedentary species. While sound curious, sudden sounds that are ~20-30 dB above ambient noise can induce a startle response, but habituation often occurs (Casper and Popper 2010).

Figure 2 from Mooney et al. 2020 may be useful to convey levels of noise perception. (b) The potential effects of noise with distance from source. Generally, noise and impact on individual animals may be greater closer to the source. Effects change with increasing distance from the source, as the acoustic signals change including that received levels decrease. Figure modified from Dooling and Blumenrath (2013)



Commented [MT10]: Consider including this figure from Mooney et al. 2020 or at least the content for preceding paragraph on interaction with and perception of sound.

Most fish sound production and habitat soundscape acoustic signatures are at frequencies below 5,000 Hz (Fish and Mowbray 1970; Zelick et al. 1999; Myrberg and Fuiman 2002). This is the range of frequencies where underwater sound propagates best. Most human-generated chronic sounds are also below 5,000 Hz (Richardson et al. 1995; Au and Hastings 2008), which is of concern as fish are very sensitive to intense sounds below 1,000 Hz. Impacts to fish include damage to ear, nerve, and lateral line tissue that can lead to sound sensing loss or threshold shifts in hearing (Jasny 1999; Heathershaw et al. 2001; Hastings and Popper 2005`). Threshold shifts result from exposure to low levels of sound for a relatively long period of time or high levels of sound for shorter periods, which may be temporary or permanent. Recovery from threshold shifts appears to require more time for fish species that vocalize (Amoser and Ladich 2003). Threshold shifts can impact a fish’s ability to carry out its life functions. Any organ with a markedly different density to seawater (e.g. swim bladder) may be susceptible to pressure-related impacts. Some of the resulting effects on fish include a rupturing of organs and death (Hastings and Popper 2005).

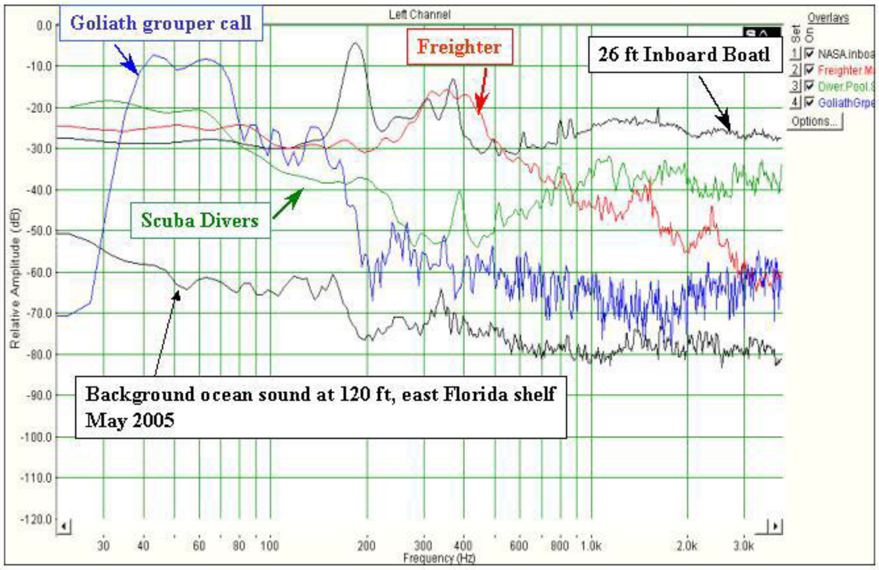


Figure 1. Illustration of the spectrum of various human activity generated and fish (Goliath grouper, *Epinephelus itajara*) sound sources. Note the low frequency sound region where most biologically important sounds are produced (<3 kHz.)

Commented [LH11]: Citation?

Commented [WL12R11]: Possibly comes from some of Dr. Laurent Cherubin's work. I looked but couldn't find the graphic quickly. Let me know if you need more help finding it.

Near field (close proximity) percussion events produced by pile driving and explosions can have a lethal impact on fish through particle motion and sound wave compression. However, the distance from the disturbance and environmental setting (water density, turbulence, etc.) undoubtedly have major influences on potential physiological effects of particle motion and need further study before they can be treated in detail (Kevin et al. 1999; Thomson et al. 2015). Behavioral response of fishes to noise from piling installation is varied; such sound has been shown to cause cod (*Gadus morhua*) to initially respond by freezing in place; cod and sole (*Solea solea*) increased swimming speed for the duration of piling noise, although some fish appeared to habituate to the repetitive noise (Andersson 2011). The lethality of underwater blasts on fish is dependent upon the intensity of the explosion; however, a number of other variables may play an important role including the size, shape, species, and orientation of the organism to the shock wave; the amount, type, and detonation depth of explosive; water depth; and bottom type (Linton et al. 1985). Fish with swim bladders are the most susceptible to underwater blasts, due to the effects of rapid changes in hydrostatic pressures on this gas-filled organ. The kidney, liver, spleen, and sinus structures are other organs typically injured after underwater blasts (Linton et al. 1985). Smaller fish are more likely to be impacted by the shock wave of underwater blasts than are larger fish, and eggs and embryos tend to be particularly sensitive (Wright 1982). However, early fish larvae tend to be less sensitive to blasts than eggs or post-larval fish, probably because the larval stages do not yet possess swim bladders (Wright 1982). Cephalopods can experience significant trauma to their statocysts, structures necessary for balance and position, at cellular and subcellular levels (André et al. 2011).

The most chronic and pervasive impacts on regional fisheries occur when human generated sounds cause behavioral changes that affect critical life history activities required to maintain healthy populations. Masking biologically significant sounds may compromise feeding, breeding, community bonding, and schooling synchronization, in addition to all of the more subtle communications between these behaviors. Anthropogenic sounds that falsely trigger fish responses may cause animals to expend energy without benefits (Stocker 2002). Several studies have indicated that increased background noise and sudden increases in sound pressure can lead to elevated levels of stress in many fish species (Hastings and Popper 2005). Chronic noise levels ≥123 dB can elicit physiological (weight loss, decreased condition, and elevated and variable heterophil:lymphocyte ratio), behavioral (increased piping and tail adjustments and reduced stationarity), and vocal (increased clicking) stress responses in the lined seahorse, *Hippocampus erectus* (Anderson et al. 2011). Similarly, scallops exposed to seismic air gun signals resulted in altered physiology (hemolymph biochemistry) and behavior (development of a flinch response and increased recessing reflex) which intensified with repeated exposure (Day et al. 2017). Additionally, playback of seismic air gun recordings induced delayed development and malformation of New Zealand scallop larvae (de Soto et al. 2013). Turbine and tidal turbine noise can obscure sounds associated with mudflats resulting in delayed metamorphosis of estuarine crabs (Carroll et al. 2017). Increased ambient noise created by watercraft activity potentially reduces the ability of marine organisms, particularly larval forms, to receive the appropriate sound cues to settle in critical habitats (Jasny 1999; Scholik and Yan 2002; Hastings and Popper 2005; Stanley et al. 2012; Holles et al. 2013; Simpson et al. 2016; Staaterman et al. 2014). Larval reef fish are attracted to some reef sound (Mann et al. 2007 and Montgomery et al. 2001); furthermore, larval coral reef fish exhibit preference for certain frequencies of biological sound depending on Family (Simpson et al. 2008). Introduction of Great Barrier Reef night sounds from an intact coral reef to nearby constructed coral reefs significantly increased juvenile damselfish recruitment (Gordon et al. 2019); whereas day sounds appeared to repel settlement-stage fish in the Philippines (Heenan et al. 2008).

Anthropogenic noise has been demonstrated to affect catch rates. Several studies indicate that catch rates of fishes decreased in areas exposed to seismic air gun blasts (Engås et al. 1996; Hastings and Popper 2005); abundance and catch rates for cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) did not return to pre-disturbance levels during the five-day monitoring period (Engås et al. 1996). These results imply that fish relocate to areas beyond the impact zone (area of highest sound intensity), which have been corroborated with visual studies on fish abundance before and after seismic surveys (Paxton et al. 2017). One study indicated that catch rates increased 30-50 km away from the noise source, showing that redistribution of fish populations can occur over broad areas (Hastings and Popper 2005). Seismic surveys may have positive, no change, or negative effect on fishery catch rates due to variable responses among fish species such as no response, dispersal, avoidance, and decreased responsiveness to bait (Carroll et al. 2017). While fish abundance can decrease due to increased

Commented [WL13]: We could definitely cite a personal communication here from Capt. Monty Hawkins, if we wanted to do so, based on his personal observations for Black Sea Bass.

Commented [MT14R13]: Monty's observations are specific to sub-bottom profiler sound. We would need to make that distinction regarding sound source. I do not recall seeing an papers provided that assess sub-bottom profiler sound effects. Not sure we want to include anecdotal observations. I am not discounting Monty's observations which are compelling, but the correlation has not been studied (at least in that specific example).

Commented [HB15]: Again, important to point out the duration of the effect.

Commented [MT16R15]: I added duration info from study (abstract).

Commented [LH17]: Missing the rest of this section of the outline:

- Cumulative impacts to fish
- Impacts to fish habitat
- Degradation of the acoustic environment and habituation (i.e. 'urban fish') that masks normal communications in fishes and makes spawning, feeding, etc. difficult (would be nice to organize and link these to the 5 categories we introduced upfront):
  - Reproduction
  - Navigation and orientation
  - Communication
  - Foraging (e.g. echolocation)
  - Protection
- Food web effects
  - Impacts of air guns on plankton
  - Impacts to forage fish
- Direct damage to habitats from sound-producing equipment/impacts of particle motion
- Resulting impacts to fisheries
  - Loss of fish on fishing grounds and resultant redistribution of fishing effort, increasing costs and possibly interactions with other types of fishing or other activities
  - Also reference direct biological impacts to fish tissues, etc., although I think we want to keep our focus on effects related to habitat
  - Potential local/regional population effects (tied to repeated reproduction impacts)

Commented [WL18R17]: Lisa, does the acoustics review team think it is important to add this section back in to the document? Seems like some important points that need to be made.

Commented [MT19R17]: Most of these are now addressed to varying extents.

anthropogenic noise, such as from wind farm operation, it is unclear the extent to which the increased noise from wind farm operation affects individual behaviors (Mooney et al. 2020).

Effect of anthropogenic noise on zooplankton is a relatively recent topic of interest. Abundance of dead larval and adult zooplankton increases two to threefold within one hour after passage of an active seismic air gun; elevated mortality extended at least 1.2 km from the air gun signal (McCauley et al. 2017). Simulations based on the McCauley et al. (2017) findings estimate a 22% reduction of zooplankton population within the survey area and declining to 14% within 15 km and 2% within 150 km (Richardson et al. 2017). In contrast, the copepod *Calanus finmarchicus* was only negatively affected when in close proximity (≤ 10 m) to an active seismic air gun (Fields et al. 2019).

Alteration of the soundscape has the potential to impact fish habitat development. Oyster larval settlement increased in presence of oyster reef habitat sounds (Lillis et al. 2013). Blue mussel respiration rates decreased resulting in altered valve gape, oxygen demand, and waste removal in response to sediment vibrations (Roberts et al. 2015). Unlike shellfish, Scleractinian corals appear resistant to soft tissue and skeletal damage after repeated exposure to a 3D seismic survey (Heyward et al. 2018). Seagrass meadows, which provide an acoustic refuge for prey species by attenuating high frequency sounds (100,000 Hz) such as those used by bottlenose dolphin (Wilson et al. 2013), may be impacted by sound. Submerged aquatic vegetation exposed to low frequency sounds (50-400 Hz at 157 ± 5 dB re 1 μPa^2) can develop physical damage to root and rhizome cellular structures; specifically amyloplasts responsible for starch production and storage, gravity sensing, and vibration reception; as well as fungal symbionts (Solé et al. 2021).

V. Case Studies

Clupeids and ultrasound

As noted above, fishes are impacted by sound both physiologically and behaviorally. Physiological responses are somewhat consistent across families. However, behavioral responses can vary depending on species-specific hearing and sensitivity to sound. Within the family Clupeidae, the subfamily Alosinae (alewife, blueback herring, menhaden, shad) have poor sound detection ability, such that sound must be loud (high intensity) in order to hear. However, they differ from other fishes in that they have evolved the ability to hear in the ultrasound range of frequencies (25,000 – 180,000 Hz) if the sound intensity is above a certain threshold (e.g. American shad – 145 dB, Mann et al. 1997). The ability may have evolved as an avoidance mechanism for echolocating predatory toothed whales (Narins et al. 2013).

Alewife responded to high frequency pulsed sound at 110,000 – 150,000 Hz above 157 dB (Dunning et al. 1992), while menhaden can detect sound at 40,000 – 80,000 Hz (Mann et al. 2001). Ultrasound pulses have been used to deter alosines from power plant intakes (Narins et al. 2013).

Because sound intensity above the clupeid sensitivity threshold of 145 dB and within the ultrasound range could impact behavior of the fish, there is concern that certain anthropogenic activities, for example, the use of Acoustic Deterrent Devices for marine mammals near pile driving activities, could impact spawning migration (Boyle & New 2018).

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Long-term monitoring of human interference with biological sound production in East Florida

Long term deployment of hydrophones in East Florida freshwater tributaries, estuaries, and continental shelf reef formations was used to isolate specific fish spawning sites for long term monitoring and continuous acoustic assessment (Gilmore 2002; Gilmore et al. 2003). The hydrophone array allowed for monitoring the impact of single freighter engine/propeller noise on subtropical reef fish. A complex, high relief (2-8 m) rock reef formation known locally as “Horseshoe Reef” was chosen for a multiple day deployment of three “Passive Acoustic Monitoring Systems” (PAMS) (Gilmore et al. 2003). PAMS were deployed on July 9, 2004 for a period of 72 hrs to continuously record all sounds between 10 and 20,000 Hz (Gilmore et al. 2003). Vessel noise interference with biological sounds was documented (Figures 2 & 3) on a mid-continental shelf reef where fishery species are known to spawn: groupers (Goliath grouper, *Epinephelus itajara*; gag, *Mycteroperca microlepis*; scamp*, M. phenax*; red grouper, *Epinephelus morio*), black sea bass, *Centropristis striatus*, and various snappers (red, *Lutjanus campechanus*; mutton, *L. analis*; and lane, *L. synagris)*. Each of these species uses acoustic signals during mating events (Mann 2006; Mann et al. 1997, 2007, 2009, 2010; Locascio and Mann 2005, 2008, 2011).

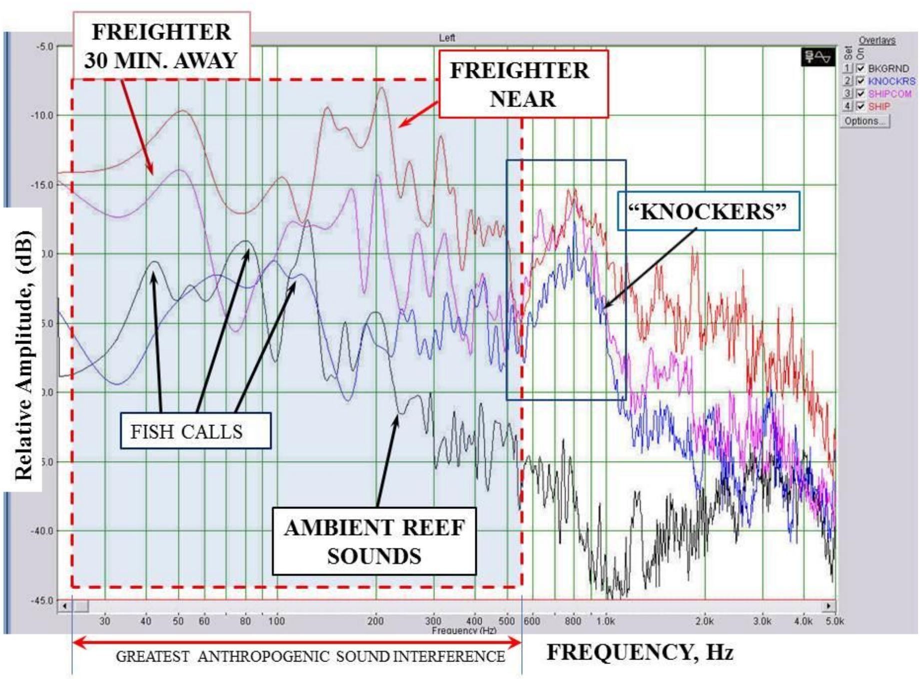

Figure 2. Spectral curves for diurnal ambient reef sounds produced on Horseshoe Reef (black curve) are compared to nocturnal biological sounds produced by an unidentified organism, labeled as “knockers”, whose acoustic pulses

center around 1,000 Hz, and fish calls (grouper/snapper) below 300 Hz (blue curve) with an approaching freighter 30 min away (purple curve), and same vessel nearby (red curve). Note that the greatest anthropogenic interference is below 600 Hz.

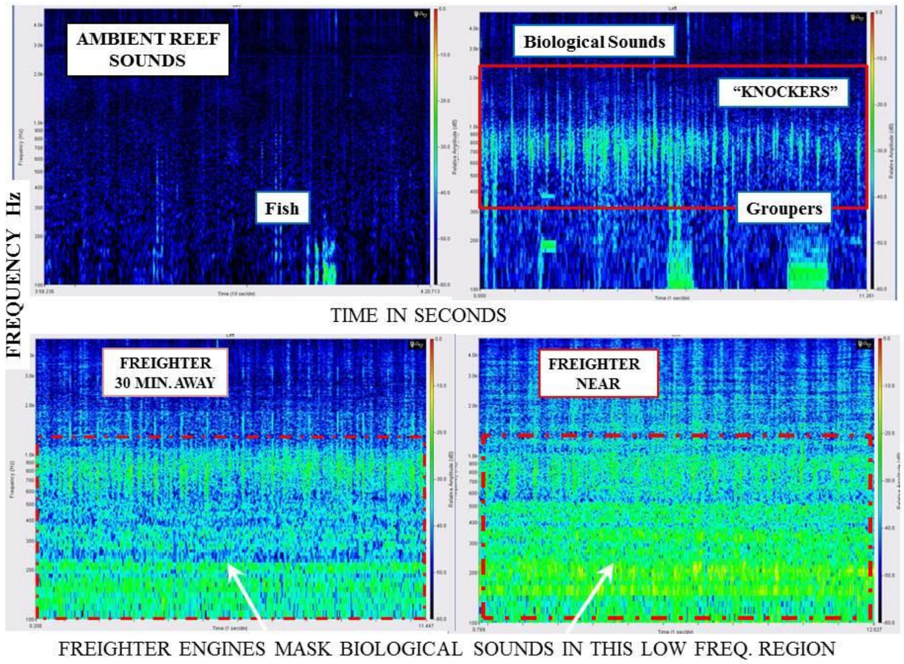

Figure 3. Horseshoe Reef sonogram depicting the same acoustic signals presented in Figure 2, revealing the greatest anthropogenic interference is from highly energetic sounds, engine and propeller noise below 600 Hz.

VI. Mitigation

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There are several measures that could be implemented to mitigate anthropogenic acoustic impacts. New technologies are available to reduce vessel noise making them less acoustically intrusive. As technology allows, use of alternative propeller design and propulsion systems such as diesel-electric hybrid, electric motors, LNG pumps, and rotor sails that are quieter than internal combustion engines can be employed. Ship generators are also a substantial source of underwater noise. Insulated or sound proofed ship hulls may be necessary in major shipping industries to further reduce acoustic impacts. When in port, vessels should connect to on-shore power systems when possible.

Marine spatial planning can be used to manage location and timing of when damaging sounds are generated. Acoustic transects can be used to isolate and map specific sites based on sound production of fishery aggregations (Gilmore 1994, 1996, 2002; Luczkovich et al. 1999; Rountree et al. 2003) as well as the broader ambient soundscape (Chou et al. 2021). For example, critical spawning and aggregation sites can be designated as off limits to vessels, dredging, seismic, construction, and other sound generating activities at night which is when spawning chorus events typically occur. These sites can be remotely monitored with vessel tracking technologies, currently in use, allowing for violating vessels to be identified.

Commented [WL23]: Do we have any examples of where a "noise exclusion window" has been put in place to protect a spawning aggregation or spawning behavior? Would be good to cite if we do have one or more examples.

Alternate seismic survey methods including higher sensitivity hydrophones, benthic stationary fibre-optic receivers, parabolic reflectors, and non-impulsive, very low frequency marine vibroseis are being studied (Chou et al. 2021).

Construction that requires pilings or some form of foundation can benefit from installation technologies such as pulse prolongation, vibropiling, foundation drilling, gravity base foundation, suction bucket jacket, mono bucket foundation, and floating foundation (Koschinski and Lüdemann 2020). When possible, one or more sound dampening measures such as bubble curtains, isolation casings, hydro sound dampers, dewatered cofferdams, and double/mandrel piles should be used (Koschinski and Lüdemann 2020). Multiple sound exposure level metrics such as cumulative, peak, single-strike, and number of strikes should be considered when evaluating the potential effect of pile driving and other impulsive sounds and establishing allowable exposure criteria (Halvorsen et al. 2011). Furthermore, deterrence strategies such as soft-start and ramp-up are intended to scare away mobile species as noise levels are gradually increased to levels that are damaging (Andersson 2011 and Chou et al. 2021).

VII. Data gaps and research needs

Commented [LH24]: Go through Popper and Hawkins 2019 for an overview of data gaps.

There is little long-term data on the effect of chronic, cumulative, anthropogenic sounds from watercraft and wind turbine generators on the behavior of invertebrates and fish, particularly at spawning sites (Hawkins and Popper 2016, 2017) and monitoring programs should be developed.

Effects from various types of anthropogenic noise including duration of and recovery from noise should be studied to determine if population level impacts exist which could affect fisheries catch rates (Carroll et al. 2017).

Anthropogenic noise may act in combination with other non-noise stressors to affect a biological response or outcome (Carroll et al. 2017). Synergistic effect of noise and non-noise stressors should be examined.

Sounds important to biological processes may be masked by anthropogenic sounds and the consequences of this disruption should be studied (Carroll et al. 2017 and Hawkins et al. 2015).

Identify the noise exposure limits and acoustic impact thresholds for various life history stages of species (Chou et al. 2021).

Subtle and long-term effects on behavior or physiology could result from persistent exposure to certain noise levels leading to an impact on the survival of fish populations (Jasny 1999; Hastings and Popper 2005). It is important to conduct integrated laboratory, behavioral, and physiological experiments under a variety of acoustic conditions, and coordinate these lab studies with field studies using the same organism. This is of critical importance as chronic sound has the potential to directly impact periodic spawning events at specific locations.

Long-term acoustic listening stations should be deployed at spawning sites where significant human activities occur to determine if mitigation measures are needed. Identifying and mapping these critical areas to create management areas limiting human generated sound is also needed.

More information on the impacts and importance of sound to fish larvae and eggs, as well as invertebrates at all life stages, is needed.

Impact of noise exposure on fish habitat development, specifically reef formation and submerged aquatic vegetation beds, is poorly understood and in need of study.

Mining the tens of thousands of hours of long duration historical recording data made by various aquatic bioacoustic investigators whose literature contributes to this review should be conducted to further identify and characterize potential human acoustic interference.

Several important data collection needs to resolve include standardization of terminology and measurement of sound exposure (Carroll et al. 2017 and Hawkins et al. 2015), a methodology for measuring particle motion in the field (Hawkins et al. 2015, Popper and Hawkins 2018), determination of appropriate particle motion metrics, improvement of particle motion sensors and mounting systems, and standards for particle motion and sound pressure sensors (Popper and Hawkins 2018).

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Improved understanding of how sound pressure and particle motion effects may differ for and among species and life history stages (Popper and Hawkins 2018).

VIII. Additional information

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The Discovery of Sound in the Sea website, https://dosits.org/ introduces users to the science and uses of Sound in the Sea. There are several major sections on the site such as The Science of Sound in the Sea, People and Sound in the Sea, and Animals and Sound in the Sea. This page focuses on resources for decision makers.

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Commented [WL29R28]: Lisa, one way to perhaps proceed is to separate Literature Cited from a Bibliography of other references which our readers may find useful, but which we didn't cite. I'd be willing to assist you in ferreting out which ones go where. Just let me know. I also can check my hard drive acoustic literature files against what we have included here, and then add any we missed to the Bibliography, if you want.

Commented [MT30R28]: I made a first pass at standardizing format and adding DOIs where possible. I made comments where there is an issue with the reference that I was not able to resolve with certainty. Yes, there are literature cited that are not referenced in the document which needs to be resolved.

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Commented [MT46]: I think the actual paper title is "A Discussion Paper On The Effects Of Explosives On Fish And Marine Mammals In The Waters Of The Northwest Territories"

Fish Habitat of Concern Designations for Fish and Shellfish Species Managed by the Atlantic States Marine Fisheries Commission

Month XX, 2021
Prepared by the ASMFC Habitat Committee and Habitat Coordinator

Introduction

The Atlantic States Marine Fisheries Commission (Commission) serves as a deliberative body that coordinates the conservation and management of the Atlantic coastal states' shared nearshore fishery resources for sustainable use. The Commission's Habitat Committee functions to promote and support cooperative interstate conservation, restoration, and protection of vital habitats for Commission-managed species. One of these functions includes the development of recommendations for Habitat Areas of Particular Concern (HAPC) for each species, which the Commission renamed 'Fish Habitats of Concern' (FHOC) in October 2017 to distinguish the Commission term from the federal term defined by the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson Act). FHOCs are a subset of fish habitat that are particularly ecologically important, sensitive, vulnerable to development threats, and/or rare. FHOCs are defined based on the same criteria as federally designated HAPCs, but since species managed only by the Commission do not fall under the Magnuson Act, their habitats are not afforded federal legal protection. Defining HAPC and FHOC for federally- and Commission-managed species, respectively, is intended to focus conservation efforts on specific habitats that are most ecologically important, vulnerable, and/or necessary to support each life stage of a species.

Commented [PR(1]: Do we have a text book example of a FHOC that is also not covered under the EFH? It would be helpful to hear a specific example.

Commented [LH2R1]: Wouldn't any species without EFH, so one that isn't jointly managed with a Council, fall in this category? For example, American lobster.

Goals

This report has two primary goals.

1. To describe the regulatory and policy context for habitat descriptions in Commission Fishery Management Plans
2. To draft text descriptions of FHOC for species managed only by the Commission.

Commission Policy on Habitat Descriptions in Fishery Management Plans

The Commission recognizes the importance of habitat conservation as a critical component of fisheries management and that thriving habitats produce abundant fish populations. While the Atlantic Coastal Fisheries Cooperative Management Act does not grant the Commission regulatory authority over habitat of commission-managed species, the Commission does require habitat descriptions be included as part of each Commission Fishery Management Plan (FMP) in recognition of the critical role habitat plays in fisheries production and ecosystem function.

Guidance and process for the development of habitat sections to be included in FMPs outlined in the ASMFC's Habitat Committee Guidance Document (2013).

The basic elements of an FMP's habitat section include:

1. Description of the Habitat;
2. Identification and Distribution of Habitat and HAPC (*since re-named FHOC*);
3. Present Condition of Habitats and HAPCs (*since re-named FHOC*);
4. Recommendations and/or Requirements for Fish Habitat Conservation/Restoration; and Information Needs/Recommendations for Future Habitat Research.

Commission-managed species are not subject to requirements imposed by the Magnuson Act which mandate designation of Essential Fish Habitat (EFH) and evaluation of federally permitted projects that may impact that habitat[1]. However, NOAA does have obligations to consult on a broader array of trust resources under the fish and wildlife coordination act, which include Commission-managed species.

Commented [KW3]: Not sure I got this quite right.

From Michelle Bachman:
Maybe someone at NMFS HCD (Lou C?) can articulate this clearly in a sentence.

Guidelines for Identifying Fish Habitat of Concern, formerly known as HAPCs

The Commission's guidelines for identifying Fish Habitats of Concern (formerly HAPCs) in FMPs are stated in the box below.

Taken from Appendix 3 to the Habitat Committee Guidance (2013, pp. 30-31). *Note: all instances of "Habitat Area of Particular Concern" have been changed to "Fish Habitat of Concern" in the text below.*

Commented [KW4]: I want to transition to using the new FHOC term. Does it make sense to do it this way?

1.4.1.2: Identification and Distribution of Fish Habitat of Concern *The intent of this subsection is to identify habitat areas or habitat area of concern that are unequivocally essential to the species in all their life stages, since all used habitats have already been identified in Subsection 1.4.1.1.* *Fish Habitats of Concern, or FHOC, are areas within EFH that may be designated according to the Essential Fish Habitat Final Rule (2002) based on one or more of the following considerations: (i) the importance of the ecological function provided by the habitat, (ii) the extent to which the habitat is sensitive to human-induced environmental degradation, (iii) whether, and to what extent, development activities are, or will be, stressing the habitat type, or (iv) the rarity of the habitat type. Descriptions of EFH are not currently being included in FMPs prepared for species solely under Commission management. The definition of FHOC is therefore modified to be areas within the species' habitat that satisfy one or more of the aforementioned criteria.* ***When an FHOC is described for a species solely under the management of the Commission, the designation does not have any regulatory authority.***

[1] Federal agencies proposing or authorizing projects within EFH areas are required to consult with the National Oceanic and Atmospheric Administration (NOAA) Fisheries to determine the impact of those projects on EFH. This EFH consultation is required only for federally managed species, not for species solely under the management authority of the Commissions. Regulatory guidelines for EFH consultations can be found at 50 C.F.R. §600.905 2015.

Please refer to the ASMFC HAPC document for a list of species under Commission management only and description of the corresponding HAPC (ASMFC 2013b)[1].

An FHOC is a subset of the "habitats" described in Subsection 1.4.1.1, and could include spawning habitat (e.g., particular river miles or river reaches for striped bass populations), nursery habitat for larvae, juveniles and subadults, and/or some amount of foraging habitat for mature adults. FHOC are geographic locations which are particularly critical to the survival of a species. Determination of the amount of habitats (spawning, nursery, subadult, adult residence, and adult migration routes) described in Subsection 1.4.1.1 that should be classified as FHOC may be difficult.

Examples of FHOC include: any habitat necessary for the species during the developmental stage at which the production of the species is most directly affected; spawning sites for anadromous species; benthic areas where herring eggs are deposited; primary nursery areas; submerged aquatic vegetation in instances when species are determined to be "dependent" upon it; and inlets such as those located between the Atlantic Ocean and bays or sounds, which are the only areas available for providing ingress by larvae spawned offshore to their estuarine nursery areas.

The extent of habitats or FHOC for a species may depend on factors such as habitat bottlenecks, the current stock size and/or the stock size for which a species Management Board and Technical Committee establishes targets, etc. Given the current state of knowledge with regard to the relationship between habitat and production of individual species, this information may not be available for many species.

If known, the historical extent of FHOC should also be included in this subsection, in order to establish a basis for Subsection 1.4.1.3. Use of GIS is encouraged to depict the historical and current extent of HAPCs, and determine the amount of loss/degradation, which will assist in targeting areas for potential restoration.

1.4.1.3: Present Condition of Habitats and Fish Habitat of Concern

This subsection should include, to the extent the information is available, quantitative information on the amount of habitat and FHOC that are presently available for the species, and information on current habitat quality. Reasons for reduction in areal extent (either current or historical), should be addressed, for example, "dam construction has eliminated twenty percent of historical spawning habitat" (ASMFC, 2008), "forage habitat bottleneck has reduced the young-of-year populations by thirty percent", or "fishing gear continues to disturb fifty percent of the forage habitat", etc.

Any habitats or FHOC that have diminished over time due to habitat bottlenecks should be incorporated to the extent information is available. Habitat bottlenecks can occur due to

[1] This document was never completed and does not exist.

Commented [KW5]: This citation is listed as:
ASMFC. 2013 pending. ASMFC Habitat Areas of Particular Concern (HAPCs). Washington (DC):
ASMFC.

I don't think this document exists. See my explanation in the footnote.

Commented [LH6R5]: This, I'm almost positive, is referring to this document.

natural disasters, fishing disturbance, impacts of development, or other complex processes that can cause habitat shifts. This subsection can further address options to reverse or restore current known habitat bottlenecks. All current threats to the species' habitat should be discussed in this subsection. If known, relative impacts from these activities should be identified and prioritized. For example, addressing hydrological alterations and their impacts are a high priority for anadromous species. These may include freshwater inflow/diversions; changes in flows due to hydropower, flood control, channel modifications, or surface/aquifer withdrawals; and saltwater flow or salinity changes due to reductions in freshwater inflows or deepening of navigation channels, which facilitate upstream salinity increases. Threats should also be assessed for their effect on the ability to recreationally and commercially harvest, consume, and market the species (e.g., heavy metals or chemical contamination which results in the posting of consumption advisories, or prohibition of commercial fisheries for a species, e.g. striped bass in the Hudson River, NY).

This subsection will serve as a basis for the development of recommended or required actions to protect the species' habitat, which will be outlined in Section 4.4. For example, the effectiveness of water quality standards should be reviewed in this subsection. If they are ineffective or inappropriate at protecting water quality at a level appropriate to assure the productivity and health of the species, then a recommendation should be included under the recommendations section (Section 4.4) for improvement of water quality standards.

Purpose of this Report

Although habitat information is required for each FMP, the amount of information compiled for each species varies, as does the extent of the underlying habitat-related science. Also, FMPs are written and amended as management needs arise, and the frequency of updates is not consistent between plans. Consequently, FHOC designations range from non-existent to specific and recent. This report was initiated to assess the quality of FHOC designations for Commission-managed species and write or update text descriptions.

The Habitat Committee drafted text descriptions of FHOC for each commission-managed species drawing on information from the current description of FHOC in the FMPs, species fact sheets, other ASMFC publications, and current literature. Descriptions were reviewed by the species technical committees for accuracy and approval.

FHOC will not be designated for species managed jointly with the Councils, instead deferring to federal designations for EFH and HACPs. FHOCs will be designated on a case by case basis for species listed under the Endangered Species Act (ESA).

As FMPs and other Commission documents are updated, 'Habitat Areas of Particular Concern (HAPC)' will be replaced with 'Fish Habitats of Concern (FHOC)' as appropriate.

Commented [KW7]: Once the updated FHOC descriptions are approved by the Policy Board, will there need to be some sort of omnibus addendum to update all of the FMPs?

Possibly for discussion by the Habitat Committee: how does designation of FHOC help protect important fish habitat? Is there any action the commission could take in the future to improve/strengthen protections for these habitats?

Commented [PR(8]: These HACPS can be particularly important for states to use during a CZM consistency review for impacts to fisheries enforceable policies or habitat enforceable policies. They can also be used in building Geographic Areas of Particular Concern within the CZM program. Not sure if these examples would be helpful in this paper.

-Is there anywhere in document to discuss shifting habitats due to sea level rise and providing room for the geographical shift?

Fish Habitats of Concern Designations

American eel (*Anguilla rostrata*)

Though no threats to the functional health of the Sargasso Sea have been reported, it is a Fish Habitat of Concern for spawning adults and eggs because this is where reproduction for the panmictic population occurs exclusively. Sargassum seaweed is currently harvested in U.S. waters by trawling primarily by one company. The harvesting of sargassum began in 1976, but has only occurred in the Sargasso Sea since 1987. Since 1976, approximately 44,800 dry pounds of sargassum have been harvested, 33,500 pounds of which were from the Sargasso Sea (SAFMC 1998). It is unknown whether this harvest is having direct or indirect influences on American eel mortality. Harvesting sargassum is being eliminated in the south Atlantic EEZ and State waters by January 1, 2001 through a management plan adopted by the South Atlantic Fisheries Management Council (SAFMC 1998). The extent of eel bycatch in these operations is unknown.

The drift of leptocephalus larvae from the Sargasso Sea towards the Atlantic coast may be impacted by changes in the ocean currents. Such changes have been predicted to be due to climate change. The potential impact on the drift of larvae is unknown at this time, but the predicted weakening of the Gulf Stream may reduce larval transport to coastal and fresh waters. Currents, primary production, and potential influence of toxins transferred from the adults to the eggs influence the success of hatch, larval migration, feeding and growth.

Glass eel survival (growth, distribution and abundance) on the continental shelf is probably impacted by a variety of activities. Channel dredging, shoreline filling, and overboard spoil disposal are common throughout the Atlantic coast, but currently the effects are unknown. Additionally, these activities may damage American eel benthic habitat. However, the significance of this impact also remains unknown. Changes in salinity in embayments, as a result of dredging projects, could alter American eel distribution.

Elver and yellow eel abundance is probably also impacted by physical changes in the coastal and tributary habitats. Lost wetlands or access to wetlands and lost access to the upper reaches of tributaries have significantly decreased the availability of these important habitats with wetland loss estimated at 54% (Tiner 1984), and Atlantic coastal tributary access loss or restriction estimated at 84% (Busch et. al 1998).

Habitat factors are probably impacting the abundance and survival of yellow and silver eel. The nearshore, embayments, and tributaries provide important feeding and growth habitat. The availability of these habitats influences the density of the fish and may influence the determination of sex. Therefore, since females may be more common in lower density settings (Krueger and Oliveira 1999, Roncrati et al. 1997, Holmgren and Mosegaard 1996, Vladykov 1966, Liew 1982, Columbo and Rossi 1978), it is crucial that the quantity and quality of these habitats be protected and restored (including upstream access). The blockage or restriction to upstream migration caused by dams reduces or restricts the amount of available habitat to support eel distribution and growth, and therefore tributary headwaters are a particular Fish Habitat of Concern. Fish that succeeded to reach upstream areas may also face significant stresses during downstream migration. If eel have to pass through turbines, mortality rates range from 10 to 60 percent (J. McCleave, U. of Maine, Person. Com.) and the amount of injury is not well documented.

American lobster (*Homarus americanus*)

Scientists, managers, and fishermen are concerned about the habitat conditions for American lobster in southern New England waters where rising water temperature has combined with degraded water quality to create conditions lethal to lobsters. Such a combination of environmental factors and events resulted in a massive die-off of lobster in western Long Island Sound in late 1999, with lesser events in later years. Continued elevated water temperatures, coupled with routine fall hypoxia and other water quality stress factors, have caused recruitment failure for the stock of lobster south of Cape Cod. North of Cape Cod, the same rise in water temperature has resulted in historically high reproduction and survival of young lobsters.

Other Fish Habitats of Concern include gravel, cobble, boulder, and embedded rock for young-of-year, juvenile, and adult life stages. Areas where these habitats are limited and in close proximity to offshore shoals are susceptible to various types of anthropogenic impact.

Atlantic croaker (*Micropogonias undulates*)

Estuaries serve as important nursery and spawning areas for Atlantic croaker. For juveniles in particular, this includes mud substrate with high detrital content. Many estuarine environments may have insufficient water quality to support Atlantic croaker habitat, due to land-based activities such as coastal development, pollution, chemical and nutrient discharges, and runoff. These activities can result in a reduction of dissolved oxygen and can create hypoxic or anoxic conditions.

Atlantic menhaden (*Brevoortia tyrannus*)

Estuarine-subtidal and riverine-tidal systems are Fish Habitat of Concern for larval and early juvenile life stages of Atlantic menhaden. Atlantic menhaden production is heavily dependent on estuarine-subtidal and riverine-tidal systems (constrained to the upstream limit of the tidal zone) and the water quality of those systems are threatened by climate change, toxicants, nutrient pollution, and altered freshwater flows. A further threat to estuarine water quality is lower dissolved oxygen associated with increasing average annual temperatures due to climate change.

Atlantic striped bass (*Morone saxatilis*)

Commented [LH9]: Note I cut out a lot of info here and focused just on the spawning and wintering grounds.

Striped bass are highly concentrated and most vulnerable in their riverine spawning areas and offshore wintering grounds. Therefore these two habitats are Fish Habitats of Concern for striped bass.

Striped bass spawn in freshwater or nearly freshwater of Atlantic Coast rivers and estuaries. Such sites provide the critical ecological function of reproduction; are sensitive to anthropogenic impacts such as dam emplacement, nutrient and sediment loading, and pollution; are susceptible to navigational dredging and other coastal development activities; and are relatively small in extent and extremely rare in comparison to the areal extent of other migratory striped bass habitats. They spawn above the tide in mid-February in Florida but in the St. Lawrence River they spawn in June or July. The bass spawn in turbid areas as far upstream as 320 km from the tidal zone (Hill, 1989). The tributaries of the Chesapeake Bay are the primary spawning areas for striped bass, but other major areas include the Hudson River, Delaware Bay and the Roanoke River. Spawning is triggered by increased water temperature (Shepherd, 2000). Spawning occurs between 10 and 23 degrees Celsius, but optimal temperature for spawning is between 17 and 19 degrees Celsius. No spawning occurs below 13 degrees Celsius or above 22 degrees Celsius (Bain, 1982). Spawning is characterized by brief excursions to the surface by females surrounded by males, accompanied by much splashing. Females release eggs in the water. This is where fertilization occurs (Raney, 1952).

A temperature range of 17-19 degrees Celsius is important for egg survival as well as for maintaining appropriate dissolved oxygen levels (Bain, 1982). Minimum water velocities of 30 cm/sec are needed to keep the eggs suspended, and fluctuations in the water velocity causes changes in the size of the oil globule surrounding the eggs (Albrecht, 1964). Without the buoyancy, the eggs sink to the bottom, where the sediment may smother them. It is possible for the eggs to hatch if the sediment is course and not sticky or muddy, but that survival is limited (Bayless, 1968). Eggs hatch from about 30 hours at 22 degrees Celsius to about 80 hours at 11 degrees Celsius (Hill, 1989).

Wintering grounds occur in the nearshore Atlantic Ocean from the Gulf of Maine south to at least Topsail Island, North Carolina. These habitats provide the critical ecological function of foraging and cover for adults most of the year; are sensitive to human-induced environmental degradation due to fishing activities, commercial navigation, offshore oil and gas exploration, and construction of offshore liquid natural gas (LNG) facilities; they are all coastal and subject to the aforementioned coastal development activities; and they are restricted to a relatively narrow band of nearshore ocean, although not as rare as spawning habitats and inlets.

Atlantic sturgeon (*Acipenser oxyrhincus*)

The Fish Habitats of Concern for Atlantic sturgeon are NOAA Fisheries' Critical Habitat designations. The designations can be found here: https://www.fisheries.noaa.gov/action/critical-habitat-designation-atlantic-sturgeon.

Commented [LH10]: Decided at spring HC meeting: Wilson will update with the latest science

Black drum (*Pogonia cromis*)

Black drum are habitat generalists, so no Fish Habitats of Concern are designated. At various life stages they can be found in 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 (seagrasses), oyster reefs and shell banks, unconsolidated bottom (soft sediments), ocean high salinity surf zones, and artificial reefs. The estuarine system as a whole serves as the species' primary nursery areas.

Cobia (*Rachycentron canadum*)

While cobia are habitat generalists, good water quality in high salinity sounds in South Carolina and Virginia where spawning aggregations occur and eggs and larvae develop is necessary. Fish Habitats of Concern should be designated for Port Royal Sound, St. Helena Sound, Beaufort, Barden's, Hatteras, and the mouth of the Chesapeake Bay, especially for the months of April through June, when extensive eggs and larvae have been documents (Lefebvre and Denson 2012). The timing of seasonal migrations and spawning aggregations appear to be driven by water temperature, therefore interannual variation in the water temperature and climate change could affect the timing of spawning and recruitment from year-to-year in the future.

Along the Atlantic coast, there are three genetically distinct groups of cobia: 1) NC/SC offshore, 2) inshore SC (Port Royal Sound and St. Helena Sound), a 3) inshore VA (Darden et al. 2014, Perkinson et al. 2019).

Horseshoe crab (*Limulus polyphemus*)

The distribution of high quality spawning beaches, which are exposed to minimal human disturbance, presents a potential bottleneck to reproductive success for this species. Beach areas that provide spawning habitat are Fish Habitats of Concern for adult horseshoe crabs. Composition of suitable spawning beaches are sand having grain sizes that range from 0.4-1.1 mm and are well drained having a moisture content of 1.5-7.5% at 9.4 cm depth. Sand must have an oxygen content >4 mg/L. Sand temperature >13.5 °C and water temperature ≥ 15 °C are required. Minimum depth of sand is 1 cm, but a sand depth > 20 cm is optimal. Beach slope is shallow at 4.5-9.5%. Presence of sulfate (from marsh peat) and anaerobic conditions will deter use of beach Delaware Division of Fish and Wildlife's 16-foot bottom trawl survey data indicated that over 99% of juvenile horseshoe crabs (<160 mm prosomal width) were taken at salinities >5 (Michels, 1997). Larger juveniles and adults use deep water habitats to forage for food, but these are not considered Fish Habitats of Concern. Of these habitats, the beaches are the most critical (Shuster 1994). Optimal spawning beaches may be a limiting reproductive factor for the horseshoe crab population.

The densest concentrations of horseshoe crabs in New Jersey occur on small sandy beaches surrounded by salt marshes or bulkheaded areas (Loveland et al. 1996). The spawning beaches within Delaware Bay are critical habitat because they support the highest density of spawning horseshoe crabs along the US Atlantic Coast. Good spawning habitat is widely distributed throughout Maryland's Chesapeake and coastal bays, including tributaries. Horseshoe crabs are restricted to areas that exceed salinities of 7 (Maryland Department of Natural Resources 1998). Prime spawning beaches within the Delaware Bay consist of sand beaches between Maurice River and the Cape May Canal in New Jersey and between Bowers Beach and Lewes in Delaware (Shuster 1994). In South Carolina and Georgia, horseshoe crabs spawn in substantial numbers on a variety of substrates including sandy beaches, salt marshes, and coarse-grained oyster shell. These are known stopover locations for red knot. While viability of eggs deposited in salt marshes are slightly reduced compared the sandy beaches, horseshoe crabs apparently use these habitats for spawning frequently in SC (Pers. Comm. SCDNR; Kendrick et al. In Review).

Commented [MRK11]: Kendrick, M.R. et al. (In Review). Assessing the Viability of American Horseshoe Crab (Limulus polyphemus) Embryos in Salt Marsh and Sandy Beach Habitats.

Jonah crab (*Cancer borealis*)
More research is needed before designating Fish Habitats of Concern for Jonah crab.

Northern shrimp (*Pandalus borealis*)
Deep, muddy basins in nearshore waters (out to 10 miles) in the southern region of the Gulf of Maine act as cold water refuges for adult shrimp during periods when most water in the Gulf reaches lethal temperatures, and is therefore a Fish Habitat of Concern. Temperature serves as a habitat bottleneck for this species. Nearshore water provides habitat for larval and juveniles stages of northern shrimp.

Red drum (*Sciaenops ocellatus*)
Red drum Fish Habitats of Concern include inlets, channels, sounds, and outer bars due to their importance for red drum spawning activity.

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, especially other sciaenids. 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.

While there is currently no supporting evidence to suggest a particular habitat type limits red drum populations, seagrass beds as especially important for newly settled individuals, and oyster reefs are especially important to red drum during the juvenile and sub-adult life stages. In fact, data from Georgia's Marine Sportfish Health Survey indicate over 80% of juvenile red drum are associated with shell habitats. Changes in water flow and conditions due to watershed activities may also limit recruitment of larvae at a local scale.

River herring and shad: alewife (*Alosa aestivalis*),blueback herring (*Alosa pseudoharengus*), American shad (*Alosa sapidissima*), and hickory shad (*Alosa mediocris*)

Fish Habitat of Concern

NOTE: Due to the dearth of information on Fish Habitat of Concern for alosine species, this information is applicable to American shad, hickory shad, alewife, and blueback herring combined. Information about one alosine species may be applicable to other alosine species and is offered for comparison purposes only. Certainly, more information should be obtained at individual FHOC for each of the four alosine species.

Metapopulation structure, meaning groups of the same species that are spatially separate, but may interact at some level, is evident in river herring. Metapopulation structure is important because individuals may be locally adapted. Adults frequently return to their natal rivers for spawning but some limited straying occurs between rivers (Jones, 2006; ASMFC, 2009a). Critical life history stages for American shad, hickory shad, alewife, and blueback herring, are the egg, prolarva (yolk-sac or pre-feeding larva), post-larva (feeding larva), and early juvenile (through the first month after transformation) (Klauda et al. 1991a,b). Spawning grounds and nursery habitat where these critical life stages grow and mature broadly includes freshwater ponds, rivers, tributaries, and inlets. The substrate preferred for spawning varies greatly and can include gravel, detritus, and submerged aquatic vegetation. Blueback herring prefer swifter moving waters than alewives do (ASMFC, 2009a). Nursery areas include freshwater and semi-brackish waters. Access to these spawning and nursery habitats may be blocked or impeded by dams or other barriers. Juvenile alosines, which leave the coastal bays and estuaries prior to reaching adulthood, also use the nearshore Atlantic Ocean as a nursery area (ASMFC 1999).

See Greene et al. 2009 for tables that detail environmental, temporal, and spatial values/factors affecting the distribution of alewife, blueback herring, American shad, and hickory shad.

Habitat quantity

Thousands of kilometers of historic anadromous alosine habitat have been lost due to development of dams and other obstructions to migration. In the 19th century, organic pollution from factories created zones of hypoxia or anoxia near large cities (Burdick 1954; Talbot 1954; Chittenden 1969). Gradual loss of spawning and nursery habitat quantity and quality, and overharvesting are thought to be the major causative factors for population declines of American shad, hickory shad, alewife, and blueback herring (ASMFC 1999).

It is likely that American shad spawned in all rivers and tributaries throughout the species' range on the Atlantic coast prior to dam construction in this country (Colette and Klein-MacPhee 2002). While precise estimates are not possible, it is speculated that at least 130 rivers supported historical runs; now there are fewer than 70 systems that support spawning. Individual spawning runs may have numbered in the hundreds of thousands. It is estimated that runs have been reduced to less than 10% of historic sizes. The 2020 American Shad Benchmark Stock Assessment Summary reported that the percentage of historic riverine habitat that is currently unobstructed varies from 4-100% in 23 river systems from Maine to Florida, with 12 systems at 75% or less unobstructed and 7 river systems at 50% or less unobstructed (see table in ASMFC 2020a). One recent estimate of river kilometers unavailable for spawning is 4.36 x 103 compared to the original extent of the runs. This is an increase in available habitat as compared with estimates from earlier years, with losses estimated at 5.28 x 103 in 1898 and 4.49 x 103 in 1960. The increase in available habitat has largely been due to restoration efforts and enforcement of pollutant abatement laws (Limburg et al. 2003).

Some states have general characterizations of the degree of habitat loss, but few studies have actually quantified impacts in terms of the area of habitat lost or degraded (ASMFC 1999). It has been noted that dams built during the 1800's and early to mid-1900's on several major tributaries to the Chesapeake Bay have substantially reduced the amount of spawning habitat available to American shad (Atran et al. 1983; CEC 1988), and likely contributed to long-term stock declines (Mansueti and Kolb 1953). North Carolina characterized river herring habitat loss as "considerable" from wetland drainage, stream channelization, stream blockage, and oxygen-consuming stream effluent (NCDENR 2000). Sixteen state and cooperative river basin habitat plans that provide greater local detail on American shad habitat and are available at http://www.asmfc.org/species/shad-river-herring.

Some attempts have been made to quantify existing or historical areas of anadromous alosine habitat, including spawning reaches. Most recently, the American shad benchmark assessed and compared the amount of currently available habitat for American shad in Atlantic Coast rivers to historic habitat availability (ASMFC 2020b). See section 2.7.2 for a description of this analysis. Results are presented for individual systems in each system stock section (Section 3), and overall coastwide results are provided in section 4.4.2. Previously, Maine estimated that the American shad habitat area in the Androscoggin River is 10,217,391 yd^2. In the Kennebec River, Maine, from Augusta to the lower dam in Madison, including the Sebasticook and Sandy rivers, and Seven Mile and Wesserunsett streams, there is an estimated 31,510,241 yd^2 of American shad habitat and 24,606 surface acres of river herring habitat. Lary (1999) identified an estimated 90,868 units (at 100 yd^2 each) of suitable habitat for American shad and 296,858 units (at 100 yd^2 each) for alewife between Jetty and the Hiram Dam along the Saco River, Maine. Above the Boshers Dam on the James River, Virginia, habitat availability was estimated in terms of the number of spawning fish that the main-stem area could support annually, which was estimated at 1,000,000 shad and 10,000,000 river herring (Weaver et al. 2003).

Although many stock sizes of alosine species are decreasing or remain at historically low levels, some stock sizes are increasing. It has not been determined if adequate spawning, nursery, and adult habitat presently exist to sustain stocks at recovered levels (ASMFC 1999).

Habitat quality

Concern that the decline in anadromous alosine populations is related to habitat degradation has been alluded to in past evaluations of these stocks (Mansueti and Kolb 1953; Walburg and Nichols 1967). This degradation of alosine habitat is largely the result of human activities. However, it has not been possible to rigorously quantify the magnitude of degradation or its contribution to impacting populations (ASMFC 1999).

Of the habitats used by American shad, spawning habitat has been most affected. Loss due to water quality degradation is evident in the northeast Atlantic coast estuaries. In most alosine spawning and nursery areas, water quality problems have been gradual and poorly defined; it has not been possible to link those declines to changes in alosine stock size. In cases where there have been drastic declines in alosine stocks, such as in the Chesapeake Bay in Maryland, water quality problems have been implicated, but not conclusively demonstrated to have been the single or major causative factor (ASMFC 1999).

Toxic materials, such as heavy metals and various organic chemicals (i.e., insecticides, solvents, herbicides), occur in anadromous alosine spawning and nursery areas and are believed to be potentially harmful to aquatic life, but have been poorly monitored. Similarly, pollution in nearly all of the estuarine waters along the East Coast has certainly increased over the past 30 years, due to industrial, residential, and agricultural development in the watersheds (ASMFC 1999).

Recommend adding maps that show spawning habitat (pull from Diadromous fish doc).

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<u>Spot (*Leiostomus xanthurus*)</u>

For larval spot, Fish Habitats of Concern include mesohaline/polyhaline SAV and brackish/saltwater marsh. Fish Habitats of Concern for juvenile and adult spot include mud and detrital substrates that have epifaunal and infauna.

Spot are strongly associated with the bottom as juveniles and adults and are seasonally dependent on estuaries. From Delaware to Florida, primary nursery habitat includes low salinity bays and tidal marsh creeks with mud and detrital bottoms. In the Chesapeake Bay and North Carolina, juveniles can also be found in eelgrass.

Spotted seatrout (*Cynoscion nebulosus*)

Commented [LH12]: Wilson to include citations.

Submerged aquatic vegetation (SAV) and salt marsh, especially where SAV is not available, are Fish Habitats of Concern for spotted seatrout. Seagrass beds provide important habitat for both juvenile and adult spotted seatrout, but are in decline along much of the Atlantic coast. Spawning takes place on or near seagrass beds, as well as sandy banks, natural sand, shell reefs, near the mouths of inlets, and off the beach (Daniel 1988; Brown-Peterson et al. 2002). 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).

Tautog (*Tautoga onitis*)

All structured habitats that are used by juvenile and adult tautog (e.g. outcrops, shells, reef, hard and soft corals, and sea whips), as well as inlets adjacent to estuaries serving as important refuge and spawning sites are Fish Habitats of Concern. SAV is a Fish Habitat of Concern for larvae and young-of-year.

Weakfish (*Cynoscion regalis*)

Commented [LH13]: Can Wilson refine based on unpublished data?

Important habitats for weakfish include nursery and spawning areas distributed along the coast from Maine through Florida. The principal spawning area is from North Carolina to Montauk, NY (Hogarth et al. 1995b), although extensive spawning and presence of juveniles has been observed in the bays and inlets of Georgia and South Carolina (pers. Comm, D. Whitaker, SCDNR).

Spawning sites include coastal bays, sounds, and the nearshore Atlantic Ocean. Nursery areas include the upper and lower portions of the rivers and their associated bays and estuaries. While disturbance to a nursery area will affect the overall coastal weakfish population it would be expected to have the greatest impact on the specific sub-population and the local fisheries that depend on it.

Egg and larval habitat include the nearshore waters as well as the bays, estuaries, and sounds to which they are transported by currents or in which they hatch.

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/seagrass bottom. In Chesapeake and Delaware Bays, they migrate to the Atlantic Ocean by December.

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.

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.