CHAPTER X. PRIORITY HABITAT ISSUES: SUBMERGED AQUATIC VEGETATION HABITAT PROTECTION AND RESTORATION WITH FOCUS ON WATER QUALITY

1.1. Issue

Protection and restoration of submerged aquatic vegetation (SAV) habitat is critical for healthy fisheries in NC while also providing additional valuable ecosystem functions and benefits that enhance coastal resiliency for aquatic life and coastal communities. Nationally, water quality and particularly water clarity is recognized as one of the most significant factors limiting SAV distribution, abundance, survival, and expansion. Regionally, on the Atlantic seaboard of the U.S., large declines of SAV have been attributed to impaired water quality in neighboring estuaries both north (Chesapeake Bay) and south (Indian River Lagoon, FL) of NC. Environmental monitoring data indicate that water quality is also having an adverse impact on SAV in NC estuarine waters, especially in the relatively lower salinity regions more directly impacted by numerous watersheds and coastal land use. Water quality impairment coupled with the expectation of rising sea level and increasing water temperatures associated with climate change, will expose all SAV in NC to multiple stressors that can limit their growth, reproduction, and distribution.

1.2. Origination

Division of Marine Fisheries, Albemarle-Pamlico National Estuary Partnership, and the Coastal Habitat Protection Plan Steering Committee

1.3. Background

Currently, NC is steward to one of the most productive and biodiverse SAV resources on the Atlantic seaboard, including the largest in-tact polyhaline and mesohaline seagrass meadows in the temperate western Atlantic.[1] SAV habitat is the foundation for ecological services that directly benefit the coastal ecosystems of NC and neighboring states.[2] These services include primary and secondary fisheries production, habitat for fish, wildlife and waterfowl, sediment and shoreline stabilization, wave energy attenuation, water purification, and carbon sequestration. Recently, it has been shown that SAV may reduce bacterial pathogens that can cause disease in humans and marine organisms.[3] All these services are important to a healthy ecosystem and provide increased community and ecosystem resilience.[4] Resource valuation studies indicate that the monetary value of the ecosystem services provided makes

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[1] Thayer, G. W., W. J. Kenworthy, and M. S. Fonseca. 1984. The ecology of eelgrass meadows of the Atlantic coast: a community profile. U.S. Fish and Wildlife Service;
Carraway, R.J. and L.J. Priddy. 1983. Mapping of submerged grass beds in Core and Bogue Sounds, Carteret County, North Carolina, by conventional aerial photography. North Carolina Department of Natural Resources and Community Development. Office of Coastal Management. Morehead City, NC;
Ferguson, R. L. and L. L. Wood, 1990. Mapping Submerged Aquatic Vegetation in North Carolina with Conventional Aerial Photography, Federal Coastal Wetland Mapping Programs (S. J. Kiraly, F. A. Cross, and f, D. Buffington, editors), U.S. Fish and Wildlife Service Biological Report 90(18):725-733;
Ferguson, R. L. and L. L. Wood, 1994. Rooted vascular beds in the Albemarle-Pamlico estuarine system. Albemarle-Pamlico Estuarine Study, Project No. 94-02, N.C. Department of Environmental Health and Natural Resources, Raleigh, N. C., and U. S. EPA, National Estuary Program;
Green, E. P., F.T. Short, and T. Frederick. 2003.World atlas of seagrasses. University of California Press;
NCDEQ (North Carolina Department of Environmental Quality). 2016. North Carolina Habitat Protection Plan. Raleigh, NC

[2] Orth, R. J., T. J. B. Carruthers, W. C. Dennison, C. M. Duarte, J. W. Fourqurean, K. L. Heck, A. R. Hughes, G. A. Kendrick, W. J. Kenworthy, S. Olyarnik, F. T. Short, M. Waycott, and S. L. Williams. 2006. A global crisis for seagrass ecosystems. Bioscience 56(12):987-996;
Lefcheck, J.S, R.J. Orth, W.C. Dennison, D.J. Wilcox, R.R. Murphy, J. Keisman, C. Gurbisz, M. Hannam, J.B. Landry, K.A. Moore, C.J. Patrick, J. Testa, D.E. Weller, and R.A. Batiuk. 2018. Long-term nutrient reductions lead to the unprecedented recovery of a temperate coastal region. Proceedings of the National Academy of Sciences. 115. 201715798. 10.1073/pnas.1715798115;

[3] Lamb, J.B., J.A.J.M van de Water, D.G. Bourne, C. Altier, M.Y. Hein, E.A. Fiorenza, N. Abu, J. Jompa, and C.D. Harvell. 2017. Seagrass ecosystems reduce exposure to bacterial pathogens of humans, fishes, and invertebrates. Science 355(6326):731-733

[4] NCDEQ (North Carolina Department of Environmental Quality). 2020. North Carolina Climate Risk Assessment and Resiliency Plan. 1601 Mail Service Center, Raleigh, NC

SAV habitat protection and restoration a priority conservation and management issue. SAV contributes to coastal resilience and economic and cultural values from the local coastal community and residents state-wide, to the millions of annual visitors to NC.[5]

Submerged aquatic vegetation is important to many aquatic organisms at some point in their life cycle, with fish and invertebrates depending on SAV for refuge, spawning, nursery, foraging, and corridor needs. Because of the seasonal abundance patterns of SAV, refuge and foraging habitat are provided almost year round for estuarine-dependent species. Fish and invertebrate use of SAV differs spatially and temporally due to distribution ranges, time of recruitment, and life histories.[6] Table x.1 provides a list of species that use SAV in NC.

Photo Credit: Jay Fleming/Getty Images

[5] Costanza, R., R. d'Arge, R. deGroot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. Oneill, J. Paruelo, R. G. Raskin, P. Sutton, and M. Vandenbelt. 1997. The value of the world's ecosystem services and natural capital. Nature 387(6630):253-260;
Barbier, E.B., S.D. Hacker, C. Kennedy, E.W. Koch, A.C. Stier, and B.R. Silliman. 2011 The value of estuarine and coastal ecosystem services. Ecological Monographs 81:169–93;
APNEP (Albemarle-Pamlico National Estuary Partnership). 2012a. Comprehensive conservation and management plan. APNEP, 1601 Mail Service Center, Raleigh, NC;
Cullen-Unsworth, L.C., L.M. Nordlund, J. Paddock, S. Baker, L.J. McKenzie, and R.K. Unsworth. 2013. Seagrass meadows globally as a coupled social-ecological system: Implications for human wellbeing. Marine pollution bulletin. 83. 10.1016/j.marpolbul.2013.06.001;
M. Nordlund, L., E.W. Koch, E.B. Barbier, and J.C. Creed. 2016. Seagrass ecosystem services and their variability across genera and geographical regions. *PLoS One*, *11*(10), e0163091.;
Ibid, 4

[6] Nelson, D. M., M. E. Monaco, E. A. Irlandi, L. R. Settle, and L. Coston-Clements. 1991. Distribution and abundance of fishes and invertebrates in southeast estuaries. NOAA/NOS Strategic Environmental Assessment Division, Silver Spring, MD
Hovel, K. A., M.S. Fonseca, D.L. Myer, W.J. Kenworthy, and P.E. Whitfield. 2002. Effects of seagrass landscape structure, structural complexity and hydrodynamic regime on macrofaunal densities in North Carolina seagrass beds. Marine Ecology Progress Series 243:11-24;
Heck, K. L., T. J. Carruthers, C. M. Duarte, A. R. Hughes, G. Kendrick, R. J. Orth, and S. W. Williams. 2008. Trophic transfers from seagrass meadows subsidize diverse marine and terrestrial consumers. Ecosystems 11:1198-1210

Table X.1. List of fish and invertebrate species documented to use submerged aquatic vegetation (SAV) habitat. Names in bold are species with relative abundances reported in literature as higher in SAV than other habitats. Note: lack of bolding does not imply non-selective use of the habitat, but lack of information.[7]

	Submerged Aquatic Vegetation (SAV) Functions[8]				
Species	Refuge	Spawning	Nursery	Foraging	Corridor
River herring*	X		X	X	X
Striped bass				X	
Yellow perch		**X**			
American eel	X		X	X	X
Bay scallop	**X**	**X**	**X**	**X**	
Blue crab	**X**		**X**	**X**	**X**
Grass shrimp	**X**		**X**	**X**	
Hard clam	**X**		**X**	**X**	
Red drum	**X**		**X**	**X**	**X**
Spotted seatrout	**X**	**X**	**X**	**X**	**X**
Weakfish	X		X	X	X
Atlantic croaker	X		X	X	X
Atlantic menhaden	X		X	X	X
Brown shrimp	**X**		**X**	**X**	**X**
Southern flounder			X	X	
Spot	X		X	X	X
Striped mullet	X		X	X	X
White shrimp	X		X	X	X
Black sea bass	X		X	X	X
Bluefish			X	X	
Gag	X		X	X	X
Kingfish spp.	X		X	X	X
Pinfish	**X**		**X**	**X**	**X**
Pink shrimp	**X**		**X**	**X**	**X**
Smooth dogfish				**X**	
Spanish mackerel			X	X	
Summer flounder			X	X	

*Includes blueback herring and alewife

There are two distinct groups of SAV ecosystems in NC distributed according to the estuarine salinity. One group thrives in fresh and low salinity riverine waters (≥10 ppt), referred to as low salinity SAV. The second group occurs in moderate to high (<10 ppt) salinity estuarine waters of the bays, sounds, and tidal creeks, referred to as high salinity SAV or seagrasses. Collectively they are referred to as SAV. These groups are distinguished by different species composition and living requirements, and have

[7] Ibid, 4

[8] ASMFC (Atlantic States Marine Fisheries Commission). 1997. Atlantic coastal submerged aquatic vegetation: a review of its ecological role, anthropogenic impacts, state regulation, and value to Atlantic coastal fisheries;
Ibid, 1;
Peterson, C. H., and N. M. Peterson. 1979. The ecology of intertidal flats of North Carolina: A community profile. U.S. Fish and Wildlife Service;
NMFS (National Marine Fisheries Service). 2002. Annual Report to Congress on the Status of U.S. Fisheries - 2001. NOAA, Silver Spring, MD;
SAFMC (South Atlantic Fishery Management Council). 1998. Final Habitat Plan for the South Atlantic Region: Essential Fish Habitat Requirements for Fishery Management Plans of the South Atlantic Fishery Management Council. South Atlantic Fishery Management Council, Charleston, SC;
Odell, J., D. H. Adams, B. Boutin, W. Collier II, A. Deary, L. N. Havel, J. A. Johnson Jr., S. R. Midway, J. Murray, K. Smith, K. M. Wilke, and M. W. Yuen. 2017. Atlantic Sciaenid Habitats: A Review of Utilization, Threats, and Recommendations for Conservation, Management, and Research. Atlantic States Marine Fisheries Commission Habitat Management 14, Arlington, VA.

characteristics similar to SAV communities found in many other estuaries in the U.S. (Table X.2).[9]

Table X.2. Average environmental conditions at locations where submerged aquatic vegetation (SAV) occurred in coastal North Carolina, 1988-1991.[10]

	Environmental parameter					
	Salinity (ppt)		Secchi depth m (ft)		Water depth m (ft)	
SAV species	Range	Average	Range	Average	Range	Average
HIGH SALINITY (<10-30 ppt)						
Eelgrass (*Zostera marina*)	10 ≥ 36	26	0.3 - 2.0 (1.0 - 6.6)	1.0 (3.3)	0.4 - 1.7 (1.3 - 5.6)	1.2 (3.9)
Shoal grass (*Halodule wrightii*))	8 ≥ 36	25	0.4 - 2.0 (1.3 - 6.6)	1.0 (3.3)	0.1 - 2.1 (0.3 - 6.9)	0.8 (2.6)
Widgeon grass (Ruppia maritima)	0 - 36	15	0.2 - 1.8 (0.7 - 5.9)	0.7 (2.3)	0.1 - 2.5 (0.3 - 8.2)	0.8 (2.6)
FRESHWATER-LOW SALINITY (0-≥10 ppt)						
Redhead grass (*Potamogeton perfoliatus*)	0 - 20	1	0.4 - 1.4 (1.3 - 4.6)	0.9 (3.0)	0.4 - 2.4 (1.3 - 7.9)	0.9 (3.0)
Wild celery (*Vallisneria Americana)*	0 - 10	2	0.2 - 2.0 (0.7 - 6.6)	0.6 (2.0)	0.2 - 2.3 (0.7 - 7.6)	1.0 (3.3)
Eurasian watermilfoil (*Myriophyllum spicatum*)	0 - 10	2	0.2 - 1.4 (0.7 - 4.6)	0.6 (2.0)	0.5 - 2.4 (1.6 - 7.9)	1.1 (3.6)
Bushy pondweed (*Najas guadalupensis)*	0 - 10	1	0.2 - 2.0 (0.7 - 6.6)	0.7 (2.3)	0.5 - 1.7 (1.6 - 5.6)	1.0 (3.3)
Sago pondweed (*Stuckenia pectinate*)	0 - 9	2	0.2 - 0.4 (0.7 - 1.3)	0.3 (1.0)	0.6 - 0.9 (2.0 - 3.0)	0.8 (2.6)

What makes NC unique from other coastal SAV ecosystems on the Atlantic seaboard is the overlapping distribution of temperate and tropical seagrasses in relatively higher salinity waters.[11] Eelgrass (*Zostera marina*) is a temperate species at the southern limit of its western Atlantic range in NC. In contrast, shoal grass (*Halodule wrightii*) is a tropical species that reaches its northernmost extent in NC. Widgeon grass (*Ruppia maritima*) has a wide salinity tolerance, but grows best in moderate salinity areas. The co-occurrence of these three SAV species is unique to NC, resulting in high coverage of shallow bottom areas in NC's estuaries, both spatially and temporally.[12] In NC, perennial and annual meadows of eelgrass are common in shallow, protected estuarine waters in the winter and spring when temperatures are cooler. However, in the summer when water temperatures are above 20 – 25°C (68 – 77°F), shoal grass is more abundant while eelgrass survives where water temperatures are relatively cooler in deeper sub-tidal areas, especially locations with continuous water flow.[13]

Submerged aquatic vegetation occurs in subtidal and intertidal areas of sheltered estuarine and riverine waters where there is unconsolidated sediment, adequate light reaching the bottom, and moderate to negligible current velocities or wave turbulence.[14] The primary factors controlling SAV distribution are

[9] Stevenson, J. C. 1988. Comparative Ecology of Submersed Grass Beds in Freshwater, Estuarine and Marine Environments. Limnology and Oceanography 33: 867–893;
Orth, R. J., W.C. Dennison, J.S. Lefcheck, C. Gurbisz, M. Hannam, J. Keisman, J.B. Landry, K.A. Moore, R.R. Murphy, C.J. Patrick, J. Testa, D.E. Weller, D.J. Wilcox. 2017. Submersed aquatic vegetation in Chesapeake Bay: sentinel species in a changing world. *Bioscience*, *67*(8), 698-712.
[10] Ibid, 1
[11] Ibid, 1
[12] Ibid, 1
[13] Ibid, 8
[14] Ibid, 1

water depth, sediment composition, wave energy, and the penetration of light through the water column.[15]

Because SAV are rooted in anaerobic sediments, they need to produce a large amount of oxygen to aerate the roots, and therefore have the highest light requirements of all aquatic plants.[16] SAV can become stressed by eutrophication and other environmental conditions which impair water transparency and/or diminish the oxygen content of water and sediments. The plant's response to these factors makes them a sensitive bio-indicator of environmental health.[17] Required light conditions can vary by species; low salinity grass species have slightly lower light requirements of >9% of surface incident light required at the leaf and >13% of surface incident light required through the surface compared to >15% and >22%, respectively, for species found in moderate to high salinity areas.[18]

High salinity SAV in coastal NC occurs on shallow back-barrier bars behind the Outer Banks (Pamlico, Core, Back, and Bogue sounds), and along the mainland shores.[19] Estuarine high salinity SAV occurs at a smaller scale in protected coastal embayments, marsh channels and along the Intracoastal Waterway, south of Bogue Inlet to around Mason's Inlet in northern New Hanover County. It has been documented in the New River, Chadwick Bay, Topsail Sound, and along the edges of creeks and the Intracoastal Waterway. In the fresh and brackish water portions of NC estuaries, low salinity SAV is abundant in larger black water systems, but rare in small black water streams, due to tannic water, irregular flows and shading from forested wetlands. SAV can be extensive in low-salinity back bays and lagoons, such as

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[15] Goldsborough, W. J., and W. M. Kemp. 1988. Light responses of submersed macrophytes: implication for survival in turbid waters. Ecology 69:1775-1786;
Kenworthy, W. J. and D. E. Haunert. 1991. The light requirements of seagrasses: proceedings of a workshop to examine the capability of water quality criteria, standards and monitoring progress to protect seagrasses. National Oceanic and Atmospheric Administration, Beaufort, NC; Ibid, 15;
Gallegos, C. L. 1994. Refining habitat requirements of submerged aquatic vegetation: role of optical models. Estuaries 17(18):187-199
Moore, K. A., H. A. Neckles, and R. J. Orth. 1996. *Zostera marina* (eelgrass) growth and survival along a gradient of nutrients and turbidity in the lower Chesapeake Bay. Marine Ecology Progress Series 142(.):247-259.
Moore, K. A., R. L. Wetzel, and R. J. Orth. 1997. Seasonal pulses of turbidity and their relations to eelgrass (*Zostera marina* L.) survival in an estuary. Journal of Experimental Marine Biology and Ecology 215(.):115-134;
Koch, E. W. 2001. Beyond light: Physical, geological, and geochemical parameters as possible submersed aquatic vegetation habitat requirements. Estuaries 24(1):1-17;
French, G. T. and K. A. Moore. 2003. Interactive effects of light and salinity stress on the growth, reproduction, and photosynthetic capabilities of *Vallisneria americana* (Wild Celery). Estuaries 26(5):1255-1268;
Havens, K. E. 2003. Submerged aquatic vegetation correlations with depth and light attenuating materials in a shallow subtropical lake. Hydrobiologia 493:173-186;
Kemp, W. M., R. Batiuk, R. Bartleson, P. Bergstrom, V. Carter, C. L. Gallegos, W. Hunley, L. Karrh, E. W. Koch, J. M. Landwehr, K. A. Moore, L. Murray, M. Naylor, N. B. Rybicki, J. C. Stevenson, and D. J. Wilcox. 2004. Habitat requirements for submerged aquatic vegetation in Chesapeake Bay: water quality, light regime, and physical-chemical factors. Estuaries 27(3):363-377;
Cho, H. J., and M. A. Poirrier. 2005. Vegetation habitat based on studies in Lake Pontchartrain, Louisiana. Restoration Ecology 13(4):623-629;
Duarte, C. M., N. Marba, D. Krause-Jensen, and M. Sanchez-Camacho. 2007. Testing the predictive power of seagrass depth limit models. Estuaries and Coasts 30(4):652-656;
Ibid, 15
[16] Ibid, 9
[17] Dennison, W. C., R. J. Orth, K. A. Moore, J. C. Stevenson, V. Carter, S. Kollar, P. W. Bergstrom, and R. Batiuk. 1993. Assessing water quality with submerged aquatic vegetation. Bioscience 43:86-94;
Biber, P. D., C. L. Gallegos, and W. J. Kenworthy. 2008. Calibration of a bio-optical model in the North River, North Carolina (Albemarle-Pamlico Sound): a tool to evaluate water quality impacts on seagrasses. Estuaries and Coasts 31(1):177-191;
APNEP (Albemarle-Pamlico National Estuary Partnership). In review. Metric report: extent submerged aquatic vegetation, high-salinity waters. APNEP, 1601 Mail Service Center, Raleigh, NC
[18] Funderburk, S. L., J. A. Mihursky, S. J. Jordan, and D. Riley. 1991. Habitat requirements for Chesapeake Bay living resources. Habitat Objectives Workgroup, Living Resources Subcommittee and Chesapeake Research Consortium with assistance from Maryland Department of Natural Resources, Solomons, MD;
USEPA (U.S. Environmental Protection Agency). 2003a. Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries. EPA 903-R-03-002. Region III Chesapeake Bay Program Office, Annapolis, MD; Ibid, 15
[19] Ferguson, R. L., I.A. Rivera, and L. L. Wood, 1989a. Seagrasses in Southern Core Sound, North Carolina. NOAA-Fisheries Submerged Aquatic Vegetation Study, Beaufort Laboratory, SEFSC, 101 Pivers Island Road, Beaufort, NC 28516;
Ibid, 4

Albemarle and Currituck sounds, tributaries of the Pamlico and Neuse rivers, and in coastal lakes like Lake Mattamuskeet (not included in SAV coverage estimates).[20]

There have been various mapping projects over the last 40+ years by several universities, and state and federal agencies. The data sources, mapping years, methodology, and extent of each individual mapping event is described in table X.3. These individual mapping events compiled together make up the historically known presence and suitable habitat of SAV along NC's coast, suggesting a historic extent of approximately 191,155 acres of SAV in public trust waters in coastal NC (Table X.4 and Figures X.1 and X.2). Additional mapping and monitoring of fresh and brackish SAV have occurred with hydroacoustic surveys, the establishment of sentinel sites in recent years in the Neuse and Pamlico rivers and Albemarle Sound,[21] and a coastwide aerial photography mapping event that occurred in 2019 and 2020 with funding from DEQ and APNEP. As these more current data layers become available they will be incorporated into this mosaic of NC SAV mapping events to better inform the known historic and current extent of SAV in NC.

Table X.3 The data sources, mapping years, methodology, and extent of each individual SAV mapping

Data Source	Methodology	Mapping years included and extent
Carraway and Priddy (1983)	Maps of SAV were created from aerial natural color photography accompanied by ground truth data for verification including location and density. Link to report	1981 (May): Bogue, Back and Core sounds
Ferguson and Wood (1994)	SAV was delineated and mapped from natural color aerial photography with a minimum mapping unit of 20m. Accompanying field inventories were conducted within study regions to verify SAV signatures and species distribution and composition. Link to report	1983 (Spring): Outer Banks from Ocracoke Inlet to Oregon Inlet 1985 (Spring): Core Sound 1988 (Spring): Core Sound, and behind Cape Hatteras from Hatteras to Avon 1990 (Fall): Currituck, Albemarle, Roanoke, and Croatan sounds, and Oregon Inlet to south of Pea Island 1991 (Fall): Pamlico River Estuary, Neuse River Estuary, western Pamlico Sound and Albemarle 1992 (Fall): Pamlico River, parts of eastern and western Pamlico Sound, and Albemarle Sound (Perquimans River)
Division Water Quality (DWQ) (1998)	Maps from aerial photography	1998: Neuse River and tributaries
Elizabeth City State University (ECSU)	Maps from color aerial photography, accompanied by field	2002 (October): Northern shoreline of Albemarle Sound and tributaries

[20] Smock, L. A., and E. Gilinsky. 1992. Coastal plain blackwater streams. Pages 271-313 *in* S. M. A. a. W. H. M. e. C.T. Hackney, editor. Biodiversity of the southeastern United States: aquatic communities. John Wiley and Sons, Inc., NY

[21] Luczkovich, J.J., 2016. Submerged Aquatic Vegetation SONAR Mapping Surveys in low-salinity habitats: Pamlico River. Final Report to Coastal Recreational Fishing License Fund. Grant No. 2015-H-048 NC Division of Marine Fisheries, Morehead City NC;
Luczkovich, J.J, and H. Zenil. 2015. Low-Salinity SAV Mapping in 2014 and 2015 using CRFL SONAR and video protocols. Preliminary Report to the Coastal Recreational Fishing License Fund. NC Division of Marine Fisheries, Morehead City, NC;
Luczkovich, J.J., 2018. Submerged Aquatic Vegetation (SAV) SONAR Mapping Surveys in low-salinity habitats: Neuse River. Final Report to Coastal Recreational Fishing License Fund. Task Order # 6795. NC Division of Marine Fisheries, Morehead City NC
Zenil, H. 2020.

Data Source	Methodology	Mapping years included and extent
	survey point data to aid in photo interpretation were produced by the ECSU Remote Sensing Program. SAV polygons were generated using "heads up" digitizing on the computer monitor.	from Big Flatty Creek to Edenton Bay 2003 (October): Back Bay, Currituck Sound, and Kitty Hawk Bay 2006: Western Albemarle Sound
North Carolina State University (NCSU) (2005)	Aerial photography from July 2005 accompanied by ground truth data.	2005 (July): Southern shore of Albemarle Sound including Bull Bay to northern Croatan Sound
Division Water Quality (DWQ) Rapid Response Team	Maps from interpolated transect data SAV was observed and collected using a garden rake from boat, traveling along the shoreline.	2005 and 2006 (June-September): field surveys were conducted for the major tributaries of Neuse and Pamlico rivers 2007 (May-August): field surveys were conducted in the Neuse and Pamlico rivers and tributaries
Marine Corps Air Station Cherry Point (2007)	Field survey's consisting of visual observations and underwater cameras in ≤ 6ft depth of water. Aerial survey using hyperspectral imagery, collected on May 14, 2007, was analyzed in ENVI software using the Spectral Angle Mapper Classification method to identify SAV.	May 14, 2007: imagery data of Piney Island was collected 2007 (June-July): field surveys for Piney Island and Brant Island Shoal
Albemarle-Pamlico National Estuary Partnership (APNEP) SAV Partners (SAV 2006-2008 Mapping)	SAV was mapped along the coast of NC and northward into Back Bay, VA by manually digitizing visible SAV from remotely-sensed imagery. Digitizing scale was typically set at 1:1,500 with a minimum mapping unit set at 15 m. Link to source metadata	This extent encompasses the coastal zone that lies within the APNEP regional boundary (Bogue Inlet north to Back Bay), as well as that which is outside of that boundary (Bogue Inlet south to Masonboro Inlet). 2006 (May-June): Bogue, Back, and Core sounds 2007 (September): Pamlico and Pungo rivers 2007 (October): coast wide except Bogue, Back and Core sounds 2008 (May-June): Bogue, Back and Core sounds
Albemarle-Pamlico National Estuary Partnership (APNEP) SAV Partners (SAV 2012-2014 Mapping)	SAV was mapped along the coast of NC by manually digitizing visible SAV from remotely-sensed imagery. Digitizing scale was typically set between 1:2,000 and 1:3,000 with a minimum mapping unit set at 15 m. Link to source metadata	This extent encompasses the high-salinity coastal zone that lies within the APNEP regional boundary (Hwy. 64 Bridge of Roanoke Sound south to Bogue Inlet). 2013 (May): Bogue, Back and North Pamlico sounds
NC Division of Marine Fisheries (DMF) (SAV 2015 Mapping)	SAV was mapped along the Southern coast of NC by manually digitizing visible SAV from	This extent encompasses the high-salinity coastal zone of Onslow Bay that lies south of Bogue Sound and

Data Source	Methodology	Mapping years included and extent
	remotely-sensed imagery. Digitizing scale was typically between 1:1,500 and 1:2,000 with a minimum mapping unit set at 15 m. [Link to source metadata]	terminating near Mason's Inlet (Onslow, Pender, and New Hanover counties) 2015 (May): Bear Inlet south to Mason's Inlet

Table X.4 Historical extent of submerged aquatic vegetation (SAV) in North Carolina (SAV Mosaic 1981 to 2015 (Figures X.1 and X.2).

Salinity Zone	SAV Region #	SAV Region Name	Historic Extent* (ac)	Percent of Historical Extent* (%)
Low	1	Currituck and Back Bay	21,613	11.3
Low	2	Albemarle Sound	12,872	6.7
Low	3	Tar-Pamlico & Neuse rivers	4,581	2.4
High	4	Pamlico Sound	712	0.4
High	5	Roanoke Sound to Ocracoke Inlet	101,739	53.2
High	6	Core Sound	36,862	19.3
High	7	Bogue Sound	10,826	5.7
High	8	Bear Inlet to Snow's Cut	1,950	1.0
High/Low	9	Cape Fear River to SC line	0	0.0
Total			**191,155**	100.0

*SAV Mosaic 1981 to 2015 (as of 6/3/2020)

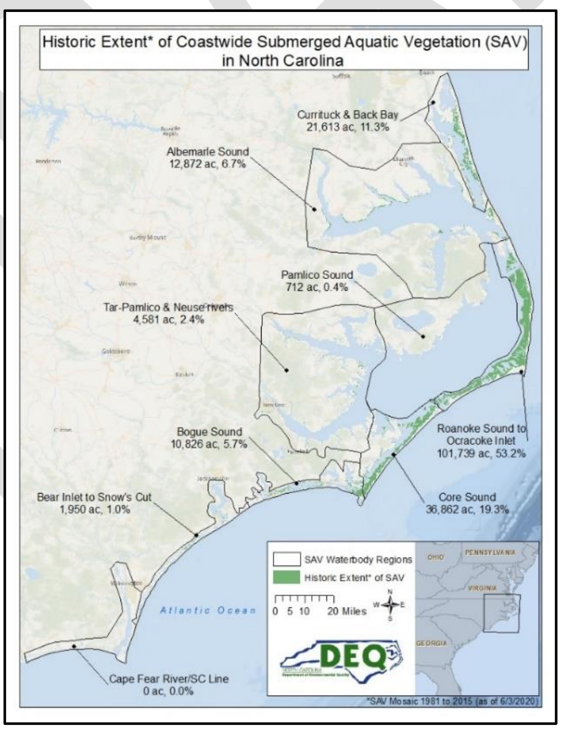
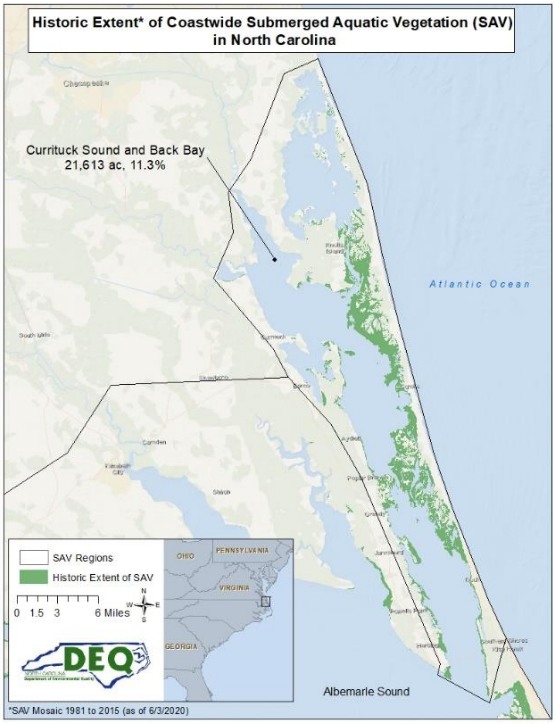
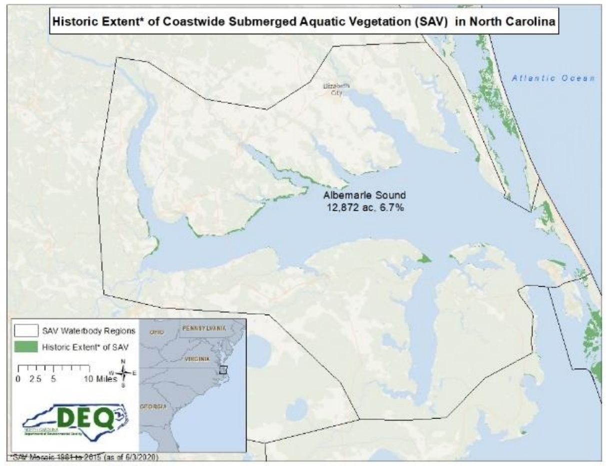


Figure X.1. Known historic extent of Submerged aquatic vegetation in North Carolina, mapped from 1981 to 2015. Absence of SAV does not suggest actual absence, as surveys have not been conducted in all areas. Presence of SAV does not reflect current state, as data dates to 1981.

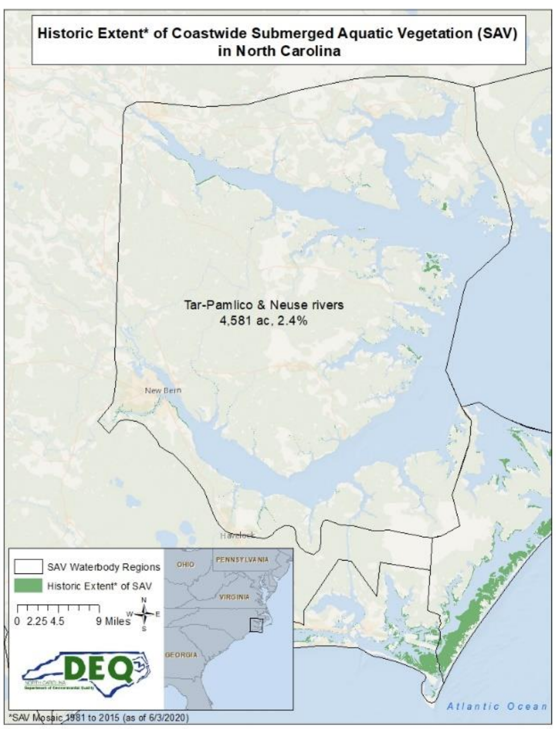
a)


Historic Extent* of Coastwide Submerged Aquatic Vegetation (SAV) in North Carolina
Currituck Sound and Back Bay
21,613 ac, 11.3%
Atlantic Ocean
SAV Regions
Historic Extent of SAV
0 1.5 3 6 Miles
Albemarle Sound
*SAV Mosaic 1981 to 2015 (as of 6/3/2020)

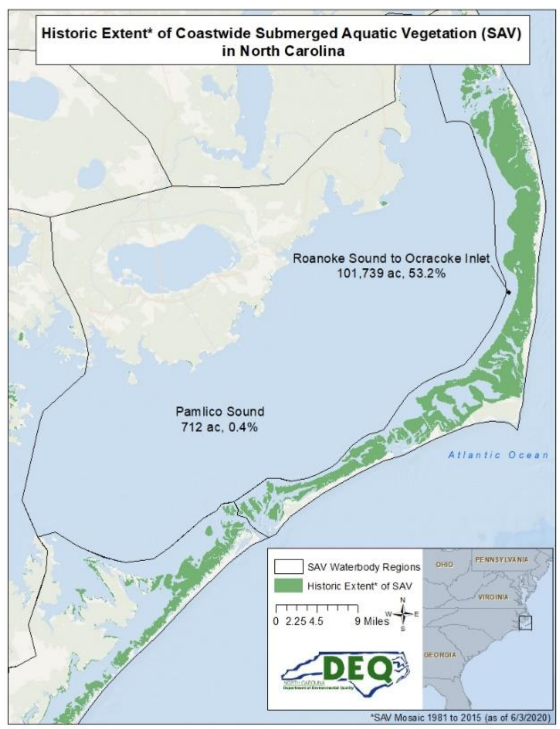
b)


Historic Extent* of Coastwide Submerged Aquatic Vegetation (SAV) in North Carolina
Atlantic Ocean
Albemarle Sound
12,872 ac, 6.7%
SAV Waterbody Regions
Historic Extent* of SAV
0 2.5 5 10 Miles
*SAV Mosaic 1981 to 2015 (as of 6/3/2020)

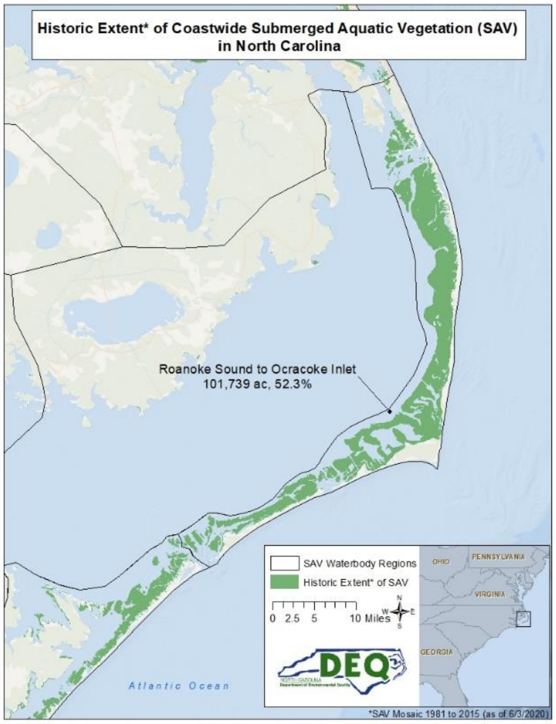
c)


Historic Extent* of Coastwide Submerged Aquatic Vegetation (SAV) in North Carolina
Tar-Pamlico & Neuse rivers
4,581 ac, 2.4%
New Bern
SAV Waterbody Regions
Historic Extent* of SAV
0 2.25 4.5 9 Miles
Atlantic Ocean
*SAV Mosaic 1981 to 2015 (as of 6/3/2020)

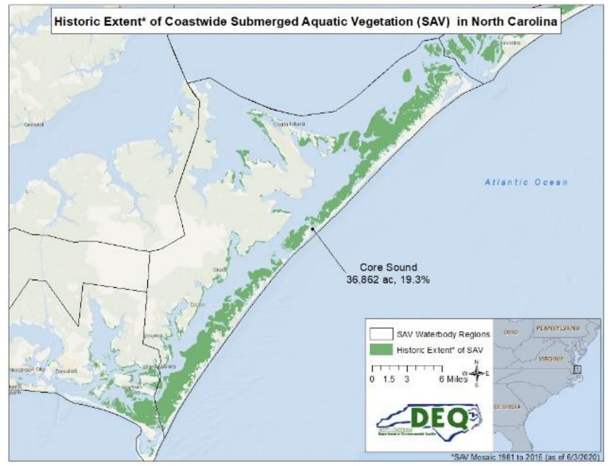
d)


Historic Extent* of Coastwide Submerged Aquatic Vegetation (SAV) in North Carolina
Roanoke Sound to Ocracoke Inlet
101,739 ac, 53.2%
Pamlico Sound
712 ac, 0.4%
Atlantic Ocean
SAV Waterbody Regions
Historic Extent* of SAV
0 2.25 4.5 9 Miles
*SAV Mosaic 1981 to 2015 (as of 6/3/2020)

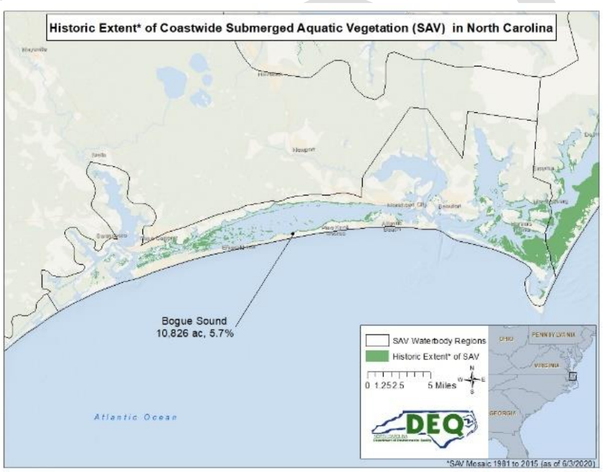
e)


Historic Extent* of Coastwide Submerged Aquatic Vegetation (SAV) in North Carolina
Roanoke Sound to Ocracoke Inlet
101,739 ac, 52.3%
Atlantic Ocean
SAV Waterbody Regions
Historic Extent* of SAV
0 2.5 5 10 Miles
DEQ
*SAV Mosaic 1981 to 2015 (as of 6/3/2020)

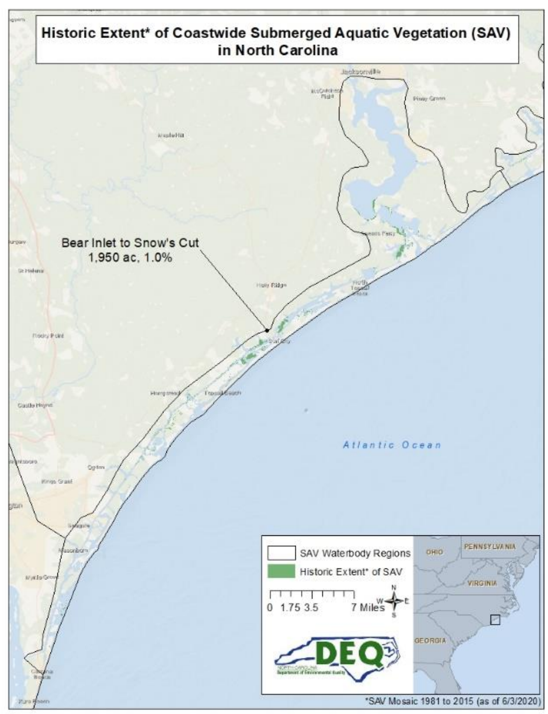
f)


Historic Extent* of Coastwide Submerged Aquatic Vegetation (SAV) in North Carolina
Atlantic Ocean
Core Sound
36,862 ac, 19.3%
SAV Waterbody Regions
Historic Extent* of SAV
0 1.5 3 6 Miles
DEQ
*SAV Mosaic 1981 to 2015 (as of 6/3/2020)

g)


Historic Extent* of Coastwide Submerged Aquatic Vegetation (SAV) in North Carolina
Bogue Sound
10,826 ac, 5.7%
Atlantic Ocean
SAV Waterbody Regions
Historic Extent* of SAV
0 1.252.5 5 Miles
DEQ
*SAV Mosaic 1981 to 2015 (as of 6/3/2020)

h)


Historic Extent* of Coastwide Submerged Aquatic Vegetation (SAV) in North Carolina
Bear Inlet to Snow's Cut
1,950 ac, 1.0%
Atlantic Ocean
SAV Waterbody Regions
Historic Extent* of SAV
0 1.75 3.5 7 Miles
DEQ
*SAV Mosaic 1981 to 2015 (as of 6/3/2020)

i)

Figure X.2. Known historic extent of Submerged aquatic vegetation in NC, mapped from 1981 to 2015 by region a) Currituck and Back Bay, b) Albemarle Sound, c) Tar-Pamlico and Neuse rivers, d) Pamlico Sound, e) Roanoke Sound to Ocracoke Inlet, f) Core Sound, g) Bogue Sound, h) Bear Inlet to Ocracoke Inlet, i) Cape Fear River to the South Carolina line. Absence of SAV does not suggest actual absence, as surveys have not been conducted in all areas. Presence of SAV does not reflect current state, as data dates to 1981.

Mapping and monitoring low salinity SAV is more difficult compared to high salinity SAV due to low water clarity in those low salinity areas of the estuary. However, despite the limited availability of historical baseline data of low salinity SAV habitat, large fluctuations in SAV abundance have been observed through hydroacoustic surveys and other sentinel site observations. Based on the most recent hydroacoustic surveys of linear SAV extent along the 1-m isobath in the Neuse, Pamlico and Albemarle river sub-estuaries, approximately 62% of the historical extent was absent from areas where SAV was previously documented (Table X.6).

Table X.6. Linear Extent (LE) data along 1-meter isobaths line for low salinity SAV based on the SAV mosaic and recent hydroacoustic surveys.[22]

Estuary	Historical* SAV LE (m)	2014-2017 SAV LE (m)	No change in SAV from historical (m)	Change in SAV LE (gain)	Change in SAV LE (loss)	Percent change in SAV LE (loss)
Albemarle Sound	117,778	90,565	56,457	+34,108	-61,321	-52.06
Tar - Pamlico River	29,223	6,036	756	+5,280	-28,467	-97.41
Neuse River	10,512	9,519	2,821	+6,692	-7,685	-73.11
Total	157,513	106,120	60,034	+46,080	-97,473	-61.88

[22] APNEP (Albemarle-Pamlico National Estuary Partnership). 2020. Clean Waters and SAV: Making the Connection Technical Workshop summary report. APNEP, 1601 Mail Service Center, Raleigh, NC https://apnep.nc.gov/our-work/monitoring/submerged-aquatic-vegetation-monitoring/clean-waters-and-sav-making-connection

Although there is less known about low salinity SAV, there are some recurring themes. These include large fluctuations in abundance, changes in species composition, a proliferation of non-native species, persistent SAV, high turbidity, extreme weather events and large amounts of precipitation, and fluctuations in salinity. This all represents an important and needed effort to develop numeric nutrient criteria, so that progress on water quality improvements can be made for the benefits of SAV.[23]

The high salinity seagrasses appear to be in better health than the low salinity SAVs. There is a good baseline of data on distribution and abundance for most of the high salinity SAV resource, along with a good understanding of species composition, persistence and resilience. However, little water quality data are collected and represents a crucial data gap.

The APNEP metric report: Extent of Submerged Aquatic Vegetation, High-Salinity Estuarine Waters (in review), provides an analysis of SAV change based on spatial coverage detected from aircraft during two survey periods: 2006-2007 (Survey 1) and 2013 (Survey 2). Survey 1 represents late spring aerial surveys of Bogue and Back Sounds and fall aerial surveys between Roanoke Island and Barden's Inlet. Survey 2 represents late spring aerial surveys between Roanoke Island and Bogue Inlet. For analysis purposes, these coastal areas are broken down into three geographic regions. The northern region is between the US Hwy 64 Bridge (Roanoke Island) to Hatteras Inlet; the central region is between Hatteras Inlet to Ophelia Inlet; and the southern region is between Barden's Inlet to Bogue Inlet.

All three regions showed declines in SAV acreage (Table X.7). However, the southern region, where there is more development and higher population densities, declined by over 10% at a rate of 1.48% loss per year. This annual loss rate in Bogue and Back Sounds equates to a projected loss of 20% of the SAV resource in that region by 2025.[24] The northern and central regions are less developed, receive less direct riverine input, and therefore had a lower estimated SAV acreage loss (Table X.7). It is concerning that no regions gained SAV based on this assessment. SAV can grow at depths generally ≤ 2.0 m, yet much of the available benthic habitat within this depth range was not occupied by SAV. An additional concern is the amount of continuous beds that were converted to patchy beds. The biggest component of the overall change in the northern region was the conversion of 15,327.5 acres (6,202.8 ha) of continuous seagrass in Survey 1 to patchy seagrass in Survey 2. Approximately 2,100 acres of continuous seagrass converted to patchy seagrass in the central and southern regions combined.[25]

[23] Ibid, 22
[24] Ibid, 22
[25] Ibid, 15

Table X.7. Net change in seagrass extent from 2006/2007 to 2013 (acres, hectares in parentheses) (Continuous=70% or greater of substrate coverage; Patchy=discontinuous coverage between 5% and 70%; Unvegetated=less than 5% substrate coverage).[26]

Conversions		Regions		
From (Survey 1)	To (Survey 2)	North (U.S. Hwy 64 Bridge at Roanoke Island to Hatteras Inlet)	Central (Hatteras Inlet to Ophelia Inlet)	South (Barden's Inlet to Bogue Inlet)
Unvegetated	Patchy	4,462.5 (1,809.5)↑	4,386.5 (1,775.2)↑	638.4 (258.4)↑
Unvegetated	Continuous	202.8 (82.1) ↑	150.4 (60.9)↑	60.1 (24.3)↑
	Gains	+4,665.3 (1,888.0)↑	+4,536.9 (1,836.0)↑	+698.5 (282.7)↑
Continuous	Unvegetated	1,894.9 (766.3)↓	401.3 (162.4)↓	88.4 (35.8)↓
Patchy	Unvegetated	7,009.4 (2,836.6)↓	4,782.3 (1,935.3)↓	1,217.5 (492.7)↓
	Losses	-8,904.3 (3,603.3)↓	-5,183.6 (2,097.7)↓	-1,305.9 (528.5)↓
Net Loss		4,238.7 (1,715.3)↓	646.7 (261.7) ↓	607.4 (245.8)↓
Beginning Total (Survey 1)		70,861 (28,676)	24,132 (9,766)	5,850 (2,367)
Ending Total (Survey 2)		66,622.3 (26,960.7)↓	23,485.3 (9,504.3) ↓	5,242.6 (2,121.2) ↓
% Change		**-5.98↓**	**-2.67↓**	**-10.38↓**
% Change yr^{-1}		**-1.08↓**	**-0.48↓**	**-1.48↓**

Waycott et al.[27] performed a global assessment of 215 studies and found that seagrasses around the world have been disappearing at a rate of 110 km^2 yr^{-1} since 1980 with an overall global average rate of decline of 1.5% y^{-1}. Although NC decline rates within the northern and central regions are lower than this global average, the higher rate of decline in Back and Bogue sounds (1.48% y^{-1}) is comparable.[28] Bogue and Back Sounds may be especially vulnerable to impairment of water quality associated with shoreline development and other anthropomorphic impacts (boat wakes, dredging, fishing gears).

1.3.1. Management of SAV in North Carolina

There are several DEQ commissions that manage activities that can directly and indirectly affect SAV. The MFC has authority over regulations of fishing practices in coastal waters through the DMF. The EMC has authority over activities that affect water quality and are implemented by DWR and DEMLR. The CRC has authority over development activities within and adjacent to the public trust and estuarine waters and coastal marshes which are implemented by the DCM. Although the WRC is not a formal participant in development of the CHPP, they oversee regulation of boating in coastal and inland waters and fishing in inland waters and are involved with the three commissions as it concerns SAV and other fisheries habitats. Additionally, the NC Department of Agriculture and Consumer Services (DA&CS) and DOT oversee activities that effect water quality via runoff.

1.3.2. Policies and Plans

There are several state, federal, and interstate policies and plans that directly or indirectly influence SAV management, restoration, and protection in NC. Table X.8 provides information on four polices with specific guidance as it pertains to monitoring, water quality, physical disturbance, land use and development, restoration, research, and education in NC. The MFC SAV Policy recognizes the

[26] Ibid, 15
[27] Waycott, M., C. M. Duarte, T. J. B. Carruthers, R. J. Orth, W. C. Dennison, S. Olyarnik, A. Calladine, J. W. Fourqurean, K. L. H. Jr., A. R. Hughes, G. A. Kendrick, W. J. Kenworthy, F. T. Short, and S. L. Williams. 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proceedings of the National Academy of Science 106(30):12377-12381
[28] Ibid 22; Ibid 15

importance of SAV to NC and calls for management guidelines to monitor and protect SAV.[29] The DENR (now DEQ) Technical Guidance Document for the Protection of Submerged Aquatic Vegetation Habitat is a document created to ensure regulatory review bodies consider SAV during the permit review process.[30] The South Atlantic Fishery Management Council (SAFMC) Policy for Protection and Enhancement of Estuarine and Marine Submerged Aquatic Vegetation (SAV) Habitat encourages the South Atlantic states to assess the status and trends in SAV and consider establishing plans that integrate monitoring and research, planning, management, education, and enforcement to protect and revitalize SAV resources.[31] The Atlantic States Marine Fisheries Commission (ASMFC) Policy was developed to communicate the necessity of conservation of coastal SAV resources because of the importance of SAV habitat to managed fish species.[32]

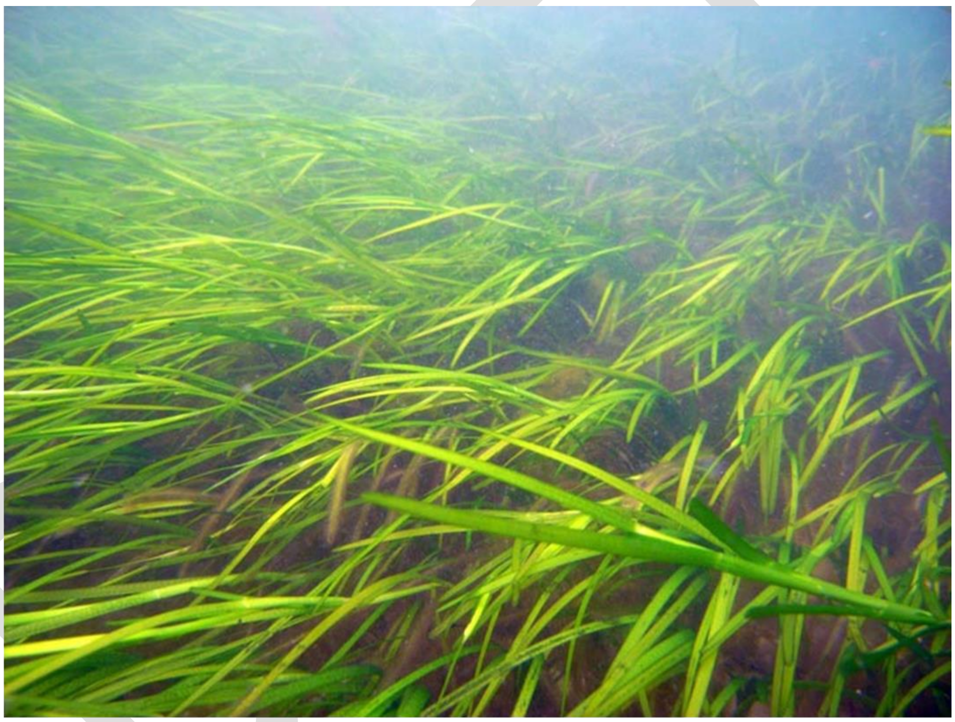


Photo credit: Martha's Vineyard Gazette

[29] NCMFC (NC Marine Fisheries Commission). 2004. Policy Statement for the Protection of SAV. Morehead City, NC
[30] NCDENR (North Carolina Department of Environment and Natural Resources). 2012. DENR Technical Guidance Document for Protection of Submerged Aquatic Vegetation Habitat. Raleigh, NC
[31] SAFMC (South Atlantic Fishery Management Council). 2014. Essential Fish Habitat Policy Statements (revised and updated). South Atlantic Fishery Management Council, Charleston, SC
[32] Havel, L.N. and ASMFC Habitat Committee. 2018. Submerged Aquatic Vegetation Policy. ASMFC Habitat Management Series No. 15, Arlington, VA

Table X.8. Existing SAV management policies from regulatory agencies affecting North Carolina.

	NC Marine Fisheries Commission[33]	NC Department of Environmental Quality[34]	South Atlantic Fishery Management Council[35]	Atlantic State Marine Fisheries Commissions[36]
Assessment & Mapping	In order to delineate and assess the distribution and health of SAV habitat, SAV beds need to be mapped and monitored.	Definition of SAV habitat is expanded for mapping and monitoring purposes.	Develop and standardize imagery acquisition and resource mapping protocols, with regional modification as necessary to achieve effective results (Yarbro and Carlson 2013). Develop and maintain a GIS database for essential habitat including SAV and use that information for assessment of trends in SAV extent (e.g., SIMM or OBIS-SEAMAP).	At a minimum, each member state should ensure the implementation of an SAV resource assessment and monitoring program which will provide a continuing quantitative evaluation of SAV distribution and abundance and the supporting environmental parameters.
Water Quality	Minimize nutrient and sediment loading to coastal waters that support existing SAV to protect adequate water quality as defined by water-column clarity in standard measurement units.		Evaluate water quality criteria needed to support SAV survival and growth and support policy making to manage quality and quantity of surface runoff. Review of state water quality standards and rules to determine if changes are needed to protect and enhance SAV.	Support and promote the development of water quality standards by the EPA and member states that can be implemented to protect SAV habitat (i.e. light attenuation, total suspended solids, chlorophyll *a*, dissolved inorganic nitrogen, dissolved inorganic phosphorus, critical life period).
Fishing Gear Disturbance	All SAV needs to be protected from all bottom-disturbing fishing and recreational gear. Sufficient buffer zones surrounding SAV beds should also be protected from disturbance to prevent impacts of sediments on growing SAV.	Dredging directly alters the bottom to conditions unfavorable for SAV growth or recolonization and should be avoided in existing and suitable bottom that has supported SAV in the past.	Review and modification of state and federal rules to ensure protection of SAV from impacts such as dredging, propeller scarring, marina and pier construction, and bottom-disturbing fishing activity.	In partnership with NOAA Fisheries and USFWS, develop technical guidelines and standards to objectively evaluate fishing gear, propeller scarring, dredging, coastal construction, and bottom fishing impacting, and develop standard mitigation strategies.
Docks & Piers		Piers and docking facilities can potentially impact SAV through construction impacts, shading, and indirect impacts from boat wakes and prop dredging. Floating docks block more sunlight due to the solid surface and lower position over the bottom and in shallow water may rest on top of the vegetation. The design, size, and location of the docking facility will determine the level of impact to SAV habitat.	Encourage states to minimize impacts to SAV by developing design criteria for docks and piers which establish minimum height, maximum width and materials.	Encourage citizen involvement in impact reporting.

[33] Ibid, 29
[34] Ibid, 30
[35] Ibid, 31
[36] Ibid, 32

	NC Marine Fisheries Commission[33]	NC Department of Environmental Quality[34]	South Atlantic Fishery Management Council[35]	Atlantic State Marine Fisheries Commissions[36]
Protection from Development	Provide adequate safeguards to prevent direct (or indirect) impacts from development projects adjacent to or connected to SAV. Assess cumulative impacts of land use and development changes in the watershed affecting SAV to identify the potential impact. Require identification of cumulative impacts as a condition of development of permit applications.	Field reps and permit reviewers should consider the potential impacts of proposed activities to SAV habitat on a case-by-case basis. Reviewers should consider the level of impact of the specific proposed activity on SAV habitat and the level of scientific documentation supporting the habitat determination (currently exists, suitable SAV habitat conditions and documented to support SAV within the past ten years).	Development of economic analyses on the economic benefits of protecting and enhancing SAV habitat.	
Habitat Restoration	Require compensatory mitigation where impacts are unavoidable. Initiate restoration programs to recoup and/or enhance lost SAV habitat.	Shoreline stabilization practices that result in increased wave energy regimes, turbidity, or sedimentation can potentially impact SAV habitat. Shoreline stabilization methods should utilize the method that would cause the least expected impact to SAV habitat if possible.	Investigate effective restoration techniques, including ecological function and cost/benefit. Development of SAV restoration guidelines for both high and low salinity SAV to accelerate successful, cost-effective SAV restoration.	Protection is preferred over restoration. Restoration programs should include establishment of habitat quality necessary for SAV prior to restoration. Restoration methods should incorporate scientifically based protocols. Restoration goals should consider potential and historical SAV spatial footprint.
Education & Outreach	Educate landowners adjacent to SAV, boaters, and other potential interested parties about the value of SAV as a habitat for many coastal fishes and invertebrates.		Design of education programs to heighten the public's awareness of the importance of SAV. An informed public will provide a firm foundation of support for protection and restoration efforts.	ASMFC and member states should promote and support public education and stewardship programs that will increase the public's knowledge of SAV, its importance as fish habitat, and commitment to SAV conservation.
Scientific Research			Research and document causes and effects of SAV losses, including cumulative impacts, watershed runoff, shoreline development, shading associated with pier and dock, development, invasive species, and extreme weather conditions (drought, tropical storms, algal blooms, etc.). Research potential effect of climate change on SAV habitat.	ASMFC and member states should promote and support those research projects which will improve our knowledge of SAV and its benefits as fish habitat.
Regulations & Enforcement Improvements		Specific guidance for permits.	The regulatory definition of SAV habitat as: shallow water habitat with appropriate sediment, depth, light penetration and wave energy, including areas without existing SAV. Review of existing regulations and enforcement to determine their effectiveness. Coordination with state resource and	ASMFC members should propose improvements necessary in state regulation and management including conditions pertaining to harvesting shellfish or finfish in SAV beds by use of mechanical means and the placement and operations of aquaculture activities to protect existing SAV beds. Encourage state agencies or departments

	NC Marine Fisheries Commission[33]	NC Department of Environmental Quality[34]	South Atlantic Fishery Management Council[35]	Atlantic State Marine Fisheries Commissions[36]
			regulatory agencies to ensure that existing regulations are being enforced.	with jurisdiction over construction activities to propose improvements necessary in state regulation and management of SAV habitats based on the standards developed in the above actions.

In addition to the policies described above, there are also various NC plans that address the importance of monitoring, protecting, and restoring the state's SAV resources. They are summarized below:

NC Wildlife Resources Commission Wildlife Action Plan (NCWAP)

This plan is a comprehensive planning tool used by the WRC to help conserve the state's fish and wildlife species and their habitats. This includes numerous recommendations for monitoring the state's SAV. The WRC received approval from the U.S. Fish & Wildlife Service (USFWS) for the comprehensive revision of the NCWAP on March 30, 2016.[37]

Albemarle-Pamlico National Estuary Partnership (APNEP) Comprehensive Conservation and Management Plan (CCMP)

The APNEP CCMP was developed using the principles of ecosystem-based management (EBM) which includes consideration of human and natural systems, an adaptive management framework, and meaningful engagement with the region's citizens to find environmental management and policy solutions. Protection and restoration efforts to improve water quality and SAV are addressed with an emphasis on assessment and monitoring to facilitate adaptive management as more knowledge is gained in the system.[38]

APNEP Submerged Aquatic Vegetation Partners Plan

This document provides a framework to guide actions and efforts in protecting and restoring SAV habitat through coordinated research, monitoring, assessment and outreach activities. It also serves as a more detailed "step-down" document that can be used to implement conservation measures specific to SAV in support of the CHPP, the WAP, and the CCMP. The goals, objectives, and actions of this plan must utilize an ecosystem approach to maximize effectiveness and efficiency.[39]

NC Aquatic Nuisance Species Management Plan

The purpose of the NC Aquatic Nuisance Species Management Plan is to improve the state's ability to address aquatic invasive and aquatic nuisance species with the goal of preventing and controlling their introduction, spread, and negative impacts. Within this plan, invasive aquatic plant species, which can have an impact on native brackish water and high salinity SAVs, are addressed. Impacts of Water Quality Impairment to

[37] NCWRC (NC Wildlife Resources Commission). 2015. North Carolina Wildlife Action Plan. Raleigh, NC
[38] APNEP (Albemarle-Pamlico National Estuary Partnership). 2012a. Comprehensive conservation and management plan. APNEP, Raleigh, NC
[39] APNEP (Albemarle-Pamlico National Estuary Partnership). 2012b. Submerged aquatic vegetation partners' action plan for the NC and southern VA coast. APNEP, Raleigh, NC

SAV.[40]

1.3.3. Impacts of Water Quality Impairment to SAV

As noted earlier, SAV is especially sensitive to water quality impairment from nutrient and sediment pollution and has been considered a “coastal canary”, serving as a valuable bio-indicator of the overall health of our coastal ecosystems.[41] Global losses of SAV are estimated to be at over 29% during the last century.[42] The impairment of water quality is one of the most widespread threats to SAV ecosystems. In the U.S., SAV along the Atlantic seaboard has experienced significant declines directly or indirectly attributed to the stressors associated with degraded water quality.[43]

The majority of SAV loss can be attributed to large-scale eutrophication (nutrient enrichment) and sedimentation, which reduces light penetration to the plants.[44] Eutrophication and/or increased sediment loads impact light available for SAV by:

- Reducing water clarity with sediment or phytoplankton associated with algal blooms;[45]
- Increasing epiphyte and/or drift algae coverage.[46]

Eutrophication of shallow estuaries can lead to proliferation of ephemeral macroalgae and filamentous green and brown algae and epiphytes that compete directly with SAV for nutrients and light.[47] Studies have found that macroalgal biomass is directly related to increased nutrient levels and that SAV loss is greater with increased macroalgae.[48] Once macroalgal blooms die, they decompose rapidly, increasing nutrient levels in the water column, stimulating phytoplankton production, further reducing light, and decreasing DO in the water and sediments. These have all been important factors in the decline of SAV up and down the Atlantic seaboard.

Chlorophyll *a* is an indicator of phytoplankton production, where high concentrations in the estuary can indicate algal blooms that in turn decrease light penetration, thus impacting SAV growth. In Albemarle Sound there has been a subtantial increase in Chlorophyll *a* over time, which is associated with

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[40] NCANSMPC (North Carolina Aquatic Nuisance Species Management Plan Committee) 2015. NC Aquatic Nuisance Species Management Plan. Raleigh, NC
[41] Ibid, 9
[42] Ibid, 2; Ibid, 27
[43] Costello, C.T. and J.W. Kenworthy. 2011. Twelve-year mapping and change analysis of eelgrass (*Zostera marina*) areal abundance in Massachusetts (USA) identifies statewide declines. Estuaries and Coasts. 34:232-242;
Lefcheck, J.S, R.J. Orth, W.C. Dennison, D.J. Wilcox, R.R. Murphy, J. Keisman, C. Gurbisz, M. Hannam, J.B. Landry, K.A. Moore, C.J. Patrick, J. Testa, D.E. Weller, and R.A. Batiuk. 2018. Long-term nutrient reductions lead to the unprecedented recovery of a temperate coastal region. Proceedings of the National Academy of Sciences. 115. 201715798. 10.1073/pnas.1715798115
[44] Ibid, 2;
Steward, J. S., and W. C. Green. 2007. Setting load limits for nutrients and suspended solids based upon seagrass depth-limit targets. Estuaries and Coasts 30(4):657-670;
Ruhl, H.A and N.B. Rybicki. 2010. Long-term reductions in anthropogenic nutrients link to improvements in Chesapeake Bay habitat. Proceedings of the National Academy of Sciences Sep 2010, 107 (38) 16566-16570. DOI: 10.1073/pnas.1003590107;
Greening, H., A. Janicki, E.T. Sherwood, R. Pribble, J.O.R Johansson. 2014. Ecosystem responses to long-term nutrient management in an urban estuary: Tampa Bay, Florida, USA. Estuarine, Coastal and Shelf Science 151: A1-A16
[45] Ibid, 43; Ibid, 44
[46] Virnstein, R. W., and L. J. Morris. 1996. Seagrass preservation and restoration: a diagnostic plan for the Indian River Lagoon. St. Johns River Water Management District, Palatka, Fl; Ibid, 43
[47] Neckles, H. A., R. L. Wetzel, and R. J. Orth. 1993. Relative effects of nutrient enrichment and grazing on epipyte-macrophyte (*Zostera marina* L.) dynamics. Oecologia (93):285-295;
McGlathery, J. K. 2001. Macroagal blooms contribute to the decline of seagrass in nutrient-enriched coastal waters. Journal of Phycology (37):453-456;
Herrera-Silveria, J.A. and S.M. Morales-Ojeda. 2009. Evaluation of the health status of a coastal ecosystem in southeast Mexico: Assessment of water quality, phytoplankton and submerged aquatic vegetation. Marine Pollution Bulletin 59:72-86.
[48] Valiela, I., J. H. J. McClelland, P. J. Behr, D. Hersh, and K. Foreman. 1997. Macroagal blooms in shallow estuaries: Controls and ecophysiological and ecosystem consequences. Limnology and Oceanography 45(5):110-1118;
Hauxwell, J., J. Cebrian, C. Furlong, and I. Valiela. 2000. Macroalgal canopies contribute to eelgrass (*Zostera marina*) decline in temperate estuarine ecosystems. Ecology 82:1007-1022.

increasing reports of cyanobacteria blooms over the same time period. Concentrations have trended moderately up and down over the last twenty years across the Albemarle-Pamlico estuarine systems. Additionally, remote sensing information corroborates a rapid increase in cyanobacteria biomass throughout the Albemarle Sound region.

Colored dissolved organic matter (CDOM) is primarily leached from decaying detritus and organic matter and gives water a brownish color. Light penetration is greatly reduced in waters with high CDOM concentrations. In general, CDOM concentrations are higher in fresh and oligohaline waters compared to polyhaline waters. In the Neuse River estuary, CDOM is increasing and may be linked to the salinity regime. As such, declines in water quality for this region could be harder to manage because they are not just directly related to nutrient enrichment.[49]

1.3.4. Case Studies of Water Quality Improvements that Benefit SAV in Chesapeake and Tampa Bays

Water quality impairment is a serious but manageable threat to SAV in NC. Water clarity for light penetration is necessary for SAV growth, and SAV survival is impacted by suspended sediments and nutrients. Coastal development expansion combined with increases in the intensity and severity of storm events, and rising sea levels, are resulting in runoff and associated increases in turbidity and nutrient loading. However, in Chesapeake Bay and Tampa Bay, improvements in water quality and resulting improved water clarity have in turn improved environmental conditions for SAV survival, growth, and propagation, allowing each system to reach targeted SAV acreage goals.

Chesapeake Bay

Loss of SAV in the shallow waters of the Chesapeake Bay from the early 1960s through the mid-1980s has been documented over time, resulting from nutrient over-enrichment and increased suspended sediment and the associated reduction of light availability to the plants.[50] Since the 1950s, the population grew around the bay, more than doubling from 8 million to over 18 million by 2020. Consequently, land development doubled and correspondingly impervious surfaces, fertilizer use (domestic and agricultural), and livestock production increased. These factors impacted water quality in the bay from nutrient enrichment and sediment loading. This, in turn, increased light attenuation (reduction) by suspended sediments, higher phytoplankton populations, and epiphytic fouling on SAV blades resulting in significant SAV population decreases.[51]

Early efforts were made to reduce point source loads, especially from wastewater treatment plants (WWTP). Examples include the Upper Patuxent River and Potomac River where WWTP upgrades to improve nitrogen and phosphorus removals were implemented in the late 1980s and early 1990s.[52] Both areas were devoid of SAV until these WWTPs were upgraded. SAV has since reappeared downstream of these plants and the reappearance has been linked to the reductions in wastewater nutrient discharges that reduced nutrient concentrations, algal biomass and light attenuation.[53]

Since establishment of the Chesapeake Bay Program partnership in 1983 with the signing of the first of

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[49] Ibid, 22
[50] Ibid, 18.
[51] Ibid, 43;
Jordan, T.E., D.E. Weller, C.E. Pelc. 2018. Effects of local watershed land use on water quality in mid-Atlantic coastal bays and subestuaries of the Chesapeake Bay. Estuaries and Coasts 41: S38-S53;
Orth, R.J., W.C. Dennison, C. Gurbisz, M. Hannam, J. Keisman, J.B. Landry, J.S. Lefcheck, K.A. Moore, R.R. Murphy, C.J. Patrick, J. Testa, D.E. Weller, D.J. Wilcox, R.A. Batiuk. 2019. Long-term Annual Aerial Surveys of Submersed Aquatic Vegetation (SAV) Support Science, Management, and Restoration. Estuaries and Coasts 2019:1-16 https://link.springer.com/content/pdf/10.1007/s12237-019-00651-w.pdf
[52] Ruhl, H.A and N.B. Rybicki. 2010. Long-term reductions in anthropogenic nutrients link to improvements in Chesapeake Bay habitat. Proceedings of the National Academy of Sciences Sep 2010, 107 (38) 16566-16570. DOI: 10.1073/pnas.1003590107; Ibid, 18.
[53] Ibid, 52; Ibid, 43; Ibid, 19.

four Chesapeake Bay watershed agreements, significant progress has been made in reducing nitrogen loads by over 60% and phosphorus loads by over 75% from hundreds of significant municipal and industrial wastewater dischargers across the six-state watershed. Atmospheric deposition of nitrogen to the bay's watershed and tidal waters has been reduced dramatically as a result of implementation of the Clean Air Act and regional efforts connecting clean air to a healthy Chesapeake Bay. Implementation of hundreds of Partnership-approved conservation practices across millions of acres of agricultural cropland, hay land, pasture and livestock operations is making measurable improvements in the thousands of miles of streams and rivers flowing into Chesapeake Bay. Widespread implementation of stormwater management practices and systems are starting to show signs of holding the line against increased flows and pollutant loads within areas of increased land development and construction. Chesapeake Bay's SAV communities have been responding in kind to these pollutant load reductions. From a low of 38,000 acres in 1984, annual baywide coordinated aerial and ground surveys mapped a high of 105,000 acres of SAV in 2017.

In response to the *Chesapeake 2000 Agreement*, the six watershed states (Delaware, Maryland, New York, Pennsylvania, Virginia, West Virginia) and the District of Columbia worked with U.S. EPA and hundreds of partners and stakeholders to develop a set of Chesapeake Bay-specific water quality criteria, designated uses and criteria attainment assessment methodologies. Agreement was reached on establishing the Program's overall strategy, including five designated uses for Chesapeake Bay's tidal waters:[54]

- Migratory fish spawning and nursery habitat;
- Open-water fish and shellfish habitat;
- Deep-water seasonal fish and shellfish habitat
- Deep-channel seasonal refuge habitat; and
- Shallow-water bay grass habitat.

Shallow-water grass habitat was defined as areas that supported underwater bay grasses in 0.5m to 2.0m depth. The designated use "protects underwater bay grasses and the many fish and crab species that depend on the vegetated shallow-water habitat provided by underwater grass beds".[55]

The *Chesapeake 2000 Agreement* also committed the signatories—state governors, DC mayor, U.S. EPA administrator, and chair of the Chesapeake Bay Commission—to adopting these criteria, designated uses and criteria attainment assessment methodologies into Delaware, Maryland, Virginia and the District of Columbia's state water quality standards regulations. These unprecedented adoptions of consistent state water quality standards across the shared multi-state body of water occurred simultaneously from 2004-2006.

For the protection of the shallow-water bay grass designated use, the three states and the District of Columbia adopted numerical water clarity criteria as well as numerical SAV restoration acreages into their respective states' water quality standards regulations.

Based on historical SAV acreage and abundance from the 1950s through 2000, the Chesapeake Bay Program partners established an SAV restoration goal of 185,000 acres.[56] An interim target to achieve 50

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[54] Ibid, 50;
USEPA (U.S. Environmental Protection Agency) 2003b. Technical Support Documentation for Identification of Chesapeake Bay Designated Uses and Attainability. EPA 903-R-03-004. Region III Chesapeake Bay Program Office, Annapolis, MD

[55] Ibid, 45

[56] Batiuk, R. A., P. Bergstrom, M. Kemp, E. Koch, L. Murray, J. C. Stevenson, R. Bartleson, V. Carter, N. B. Rybicki, J. M. Landwehr, C. Gallegos, L. Karrh, M. Naylor, D. Wilcox, K. A. Moore, S. Ailstock and M. Teichberg. 2000. *Chesapeake Bay Submerged Aquatic Vegetation Water Quality and Habitat-Based Requirements and Restoration Targets: A Second Technical Synthesis.* CBP/TRS 245/00 EPA 903-R-00-014. U.S. EPA Chesapeake Bay Program, Annapolis, MD.

percent of the 185,000-acre restoration goal (92,500 acres) by 2017 was set and met in 2015. By 2017, there was over 100,000 acres in the bay, meeting the 50 percent interim goal.[57] The baywide SAV restoration goal was broken down into acreages for each of the 106 Chesapeake Bay segments. It was these bay segment-specific SAV restoration acreages which were promulgated into the respective states' water quality standards regulations.

In order to achieve these grass restoration goals, water clarity criteria were developed by the Chesapeake Bay Program partners and published by the EPA on behalf of the partnership based on:

- Light requirements for underwater grasses;
- Factors that contribute to light attenuation;
- Epiphyte contribution to light attenuation on leaf surface; and
- Minimal requirements for light penetration through the water column and leaf surface.

Based on research, literature review and modeling, the minimal amount of light necessary for SAV was ≥20 percent light availability through the water column (PLW) for polyhaline and mesohaline species. For tidal fresh and oligohaline species, >13 percent light availability was necessary.[58]

In the Chesapeake Bay, linking biological responses of SAV to improved water quality management over time was possible through the availability of annual digital SAV maps based on aerial overflights with ground-based surveys for species distribution delineations conducted annually since 1984. These maps, along with extensive land cover and land use mapping and water quality data collected through a coordinated monitoring network within the Chesapeake Bay and across its watershed enabled monitoring of SAV abundances, which served as an indicator of nutrient and sedimentation inputs into the bay. The positive feedback of increased light availability leading to increased SAV abundance led to lower suspended chlorophyll, particulates and turbidity, resulting in further increased water clarity.[59]

Tampa Bay

As with the Chesapeake Bay, Tampa Bay has also experienced environmental degradation by similar stressors as a result of urbanization and development.[60] Discharges of poorly treated wastewater into the bay, an abundance of small package plants and aging septic systems, and stormwater runoff and industrial discharges all led to algal blooms that peaked in the 1970s in the upper reaches and expanded throughout the Bay. This resulted in approximately 44% loss of SAV between 1950 and 1990 in the bay due to decreased light attenuation caused by algal blooms.

Because of these issues, citizens demanded that the government take action to restore Tampa Bay. In the early 1970s, an ambient water quality monitoring program was established and is still in place today. Municipal WWTPs were required to provide advanced water treatment in Tampa Bay, which reduced this source of nitrogen loading by 90 percent.[61] Storm-water regulations were also put in place by the

[57] Ibid, 22

[58] Ibid, 56; Ibid, 54;

Kemp, W. M., R. Batiuk, R. Bartleson, P. Bergstrom, V. Carter, C. L. Gallegos, W. hunley, L. Karrh, E. W. Koch, J. M. Landwehr, K. A. Moore, L. Murray, M. Naylor, N. B. Rybicki, J. C. Stevenson, and D. J. Wilcox. 2004. Habitat requirements for submerged aquatic vegetation in Chesapeake Bay: water quality, light regime, and physical-chemical factors. Estuaries 27(3):363-37

[59] Ibid, 19

[60] Greening, H. and A. Janicki. 2006. Toward reversal of eutrophic conditions in a subtropical estuary: Water quality and seagrass response to nitrogen loading reductions in Tampa Bay, Florida, USA. Environmental Management 38(2):163-178;

Greening, H., A. Janicki, E.T. Sherwood, R. Pribble, J.O.R Johansson. 2014. Ecosystem responses to long-term nutrient management in an urban estuary: Tampa Bay, Florida, USA. Estuarine, Coastal and Shelf Science 151: A1-A16;

Latimer, J.S., Trettin, C.C., Bosch, D.D., and Lane, C.R., eds. 2019. Working watersheds and coastal systems; research and management for a changing future-Proceedings of the Sixth Interagency Conference on Research in the Watersheds. July 23-26, 2018, Shepherdstown, WV. E-Gen Tech Rep SRS-243. Asheville NC: US Department of Agriculture Forest Service, southern Research Station. 211; Ibid 22

[61] Ibid, 60

State of Florida that reduced nitrogen loading from non-point sources.

During the 1990s, numerous agencies around the Tampa Bay area worked to adopt water quality management strategies that linked nitrogen loading management to SAV restoration and protection. With the formation of the Tampa Bay Estuary Program, nitrogen management became the focus in order to benefit SAV restoration through the Tampa Bay Nitrogen Management Consortium.[62] Over fifty stakeholders, consisting of local, state, and federal partners began working with diverse private entities such as electric utilities, phosphate mining companies, and the shipping industry to reduce nitrogen loading in the bay. Through this Consortium, hundreds of projects were implemented by voluntary actions to collectively reduce or prevent nitrogen from entering the bay.[63]

To improve and maintain water quality conditions in the face of growing populations around the bay, numeric targets were established for chlorophyll *a* concentration and light penetration levels based on light requirements of SAV. Models were used to relate nitrogen loads to chlorophyll *a* concentrations within four bay segments. These models were then used to develop nitrogen loading targets necessary to restore SAV in each of the four bay segments. Over time, periodic evaluations of these targets have occurred using an adaptive management strategy through assessment of both seagrass coverage and water quality improvements. Based on the assessment, if targets are met, the Consortium continue to implement projects as planned and continue monitoring. If standards are not met, and based on the level of water quality conditions, some form of management action is required.[64]

As a result of the efforts made by the numerous partners within the Consortium and the Tampa Bay Estuary Program, Tampa Bay has experienced a decrease in nitrogen loading to approximately one third of estimated levels from the 1970s, even as populations around the bay have increased. This has resulted in decreases of chlorophyll *a* and increases in water clarity to the extent that seagrass coverage now exceeds the 1950s target estimates, reaching the SAV recovery goal of 38,000 acres by 2016. It should be recognized that the collaboration of numerous regulatory, non-regulatory, industry and municipalities are responsible for the overall water quality in the bay.[65]

1.3.5. Nutrient Control in the Albemarle Sound/Chowan River

The Albemarle Sound and the Chowan River have experienced an increase in the number of algal blooms over the past several years. Based on sampling in Chowan River, a tributary of the Sound, organic nitrogen has increased over time. In Potecasi Creek, a tributary in the Chowan River, nutrient patterns shifted around 2002, with nitrate concentrations declining and total nitrogen increasing. The cause for this is unknown. In the Nottaway River, total nitrogen has increased similar to Potacasi Creek, but to a lesser extent. In the Blackwater River, there has been a decline in nitrogen over time, in contrast to what is occurring in Chowan River. There were initial thoughts that the increases were from Virginia, but data suggest this is a NC issue.[66] Other potential causes being examined are runoff from land use activities, particularly agriculture, and subsurface flow of nutrient enriched groundwater into the estuary. This could occur since all WWTPs in the Chowan River watershed utilize land application.

There were several algal blooms in the Chowan, Perquimans, and Pasquotank Rivers in 2019, with different toxins encountered, including microcystin. Concentrations were highly elevated in some blooms (Arrowhead Beach, Indian Creek, Leary Landing), requiring health advisories. In October of 2019, there were six reports of blooms near Elizabeth City. These blooms are starting to begin earlier in the

[62] Ibid, 60
[63] Ibid, 22
[64] Ibid 60; Ibid 22
[65] Ibid 60; Ibid 22
[66] Brian Wrenn, NCDWR, personal communication

year and are lasting longer (Brian Wrenn, NCDWR, 2019). The DWR is actively working to develop appropriate nutrient criteria for the waters of the state. The DWR's goal is to develop scientifically defensible criteria based primarily on the linkage between nutrient concentrations and protection of designated uses. The criteria for each waterbody will be coordinated with other waterbodies to ensure consistency across the state and protect downstream uses.

NC's nutrient management strategies have historically been driven by concerns over algal blooms and fish kills, not SAV decline. Early nutrient reduction efforts included the implementation of a statewide chlorophyll *a* standard in 1978, a nutrient sensitive waters (NSW) classification in 1979, and a phosphorus detergent ban in 1988.[67] The NC Nutrient Criteria Development Plan (NCNCDP) outlines several steps to establish nutrient criteria within the state in two phases.[68] This includes the creation of a Scientific Advisory Council (SAC) and the identification of three geographic areas within the state for development of nutrient criteria. The plan also establishes a process through which the DWR will evaluate nutrients throughout NC. One of the three areas identified is the estuarine region of the Albemarle Sound.

Phase I nutrient criteria development for the Albemarle Sound was completed in 2016 where a nutrient workgroup was convened and met over a period of two years to develop nutrient criteria recommendations and research needs. Although no consensus was reached on nutrient criteria recommendations, research needs were identified and a report generated. North Carolina is now moving into Phase II of the process and has convened a SAC to review research and nutrient criteria proposed in Phase I, assess the quality and relevance of nutrient data, identify data gaps and help develop a management approach for Albemarle Sound. Management actions will be focused on wastewater, agriculture, riparian buffer protection, stormwater runoff from new and existing development, and nutrient trading. Criteria will be regulatory goals for the waterbodies and are aimed at protecting designated uses such as aquatic life, using SAV habitat as a biological endpoint.

1.3.6. Other Contributing Factors

<u>Climate Change</u>

As climate change continues, forecast scenarios predict that NC coastal waters will experience warming temperatures and rising sea levels and increasing risk for storminess and coastal flooding.[69] Coastal NC has had 36 tropical cyclones over the past two decades that, based on their duration, wind speed, precipitation, and geographic track, have impacts on hydrodynamic flows and nutrient and carbon

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[67] Ibid 22

[68] NCDWR (North Carolina Division of Water Resources). 2014. North Carolina Nutrient Criteria Development Plan. Report to the US Environmental Protection Agency Region 4. Raleigh, NC
https://files.nc.gov/ncdeq/Water%20Quality/Environmental%20Sciences/ECO/NutrientCriteria/North%20Carolina_NCDP_June_20_2014B.pdf;
NCDWR (North Carolina Division of Water Resources). 2019. North Carolina Nutrient Criteria Development Plan V. 2. Report to the US Environmental Protection Agency Region 4. Raleigh, NC

[69] Paerl, H.W., J.R. Crosswell, B.Van Dam, N.S. Hall, K.L. Rossignol, C.L. Osburn, A.G. Hounshell, R.S. Sloup, and L.W. Harding. 2018. Two decades of tropical cyclone impacts on North Carolina's estuarine carbon, nutrient and phytoplankton dynamics: implications for biogeochemical cycling and water quality in a stormier world. Biogeochemistry 141, 3(2018):307-332.
https://lnba.net/system/files/Paerl%20biogeochmistry%202018.pdf
Paerl, H.W., Hall, Hounshell, A.G., Luettich, R.A., Rossignol, K.L., Osburn, C.L., Bales, J. 2019. Recent increase in catatrophic tropical cyclone flooding in coastal North Carolina, USA: long-term observations suggest a regime shift. Scientific Reports. 9:10620
https://www.nature.com/articles/s41598-019-46928-9
Kunkel, K.E., D.R. Easterling, A. Ballinger, S. Bililign, S.M. Champion, D.R. Corbett, K.D. Dello, J. Dissen, G.M. Lackmann, R.A. Luettich, Jr., L.B. Perry, W.A. Robinson, L.E. Stevens, B.C. Stewart, and A.J. Terando, 2020: North Carolina Climate Science Report. North Carolina Institute for Climate Studies, 233 pp. https://ncics.org/nccsr
NCDEQ (North Carolina Department of Environmental Quality). 2020. North Carolina Climate Risk Assessment and Resiliency Plan. 1601 Mail Service Center, Raleigh, NC

loading to the Pamlico Sound system.[70] A review of these storms by Paerl et al.[71] on the impacts to the Neuse River and to the Pamlico Sound demonstrates that major storms can double annual nitrogen and triple phosphorus loading and can be a significant source of CO_2 releases into the atmosphere from extreme winds. Historic flooding also provides large inputs of carbon from the watershed disrupting the carbon balance and leading to sustained CO_2 releases into the atmosphere for months. Phytoplankton patterns were also influenced by the loading and flushing of nutrients based on the quantities of freshwater discharged. High freshwater discharges will flush maximum nutrient loads, but these flushing rates can also exceed phytoplankton growth rates and cause temporary reductions in phytoplankton biomass. However, as flushing rates tend to be moderate in the days to weeks following a storm, phytoplankton can take advantage of elevated nutrients delivered during the storm and form blooms.

The warming ocean waters contribute to storm intensity, increased precipitation, slowed storm movement, and, therefore, provide more opportunity for heavy precipitation over a particular area for a longer period of time.[72] It has also been observed that tropical cyclone paths are shifting northward, making NC more susceptible to these events. Extreme precipitation events result in flooding and high loading of organic matter, including organic nitrogen and phosphorus. This in turn fuels phytoplankton production, resulting in algal blooms and associated hypoxia. Runoff from agricultural fields and urban development also add to the contamination of floodwaters. This leads to the consideration that there may be a regime shift in heavy precipitation and tropical cyclone flooding and associated ecosystem impacts. NC has experienced very high precipitation since the late 1990s with increasingly high precipitation events, including those associated with tropical cyclones that could have major ramifications for hydrology, carbon, nutrients, habitat and water quality in NC.[73]

If we are seeing a regime shift in storms due to rising temperatures, it can also be expected to see species distribution shifts within our SAV system. As mentioned earlier, NC is home to two species of high salinity SAV existing at the edges of their geographic distributions; the tropical shoal grass where NC is the northernmost range and eelgrass, a temperate grass where NC is the southernmost range. As the climate changes and the waters warm, this could alter the growth, abundance and distribution of eelgrass with the potential for the southern range to shift north. Based on models of the impacts of sea surface temperatures, sea surface salinity, and sea ice on eelgrass distribution under different carbon emission scenarios, it is projected that climate change could possibly result in extirpation of eelgrass in NC by the end of the 21st century.[74] Should there be no changes to carbon emissions, this study suggests that eelgrass will be extirpated in NC and Chesapeake Bay with the new southern range as far north as Long Island Sound by 2100. It is important to note that this study used very few eelgrass occurrence records from NC's estuarine system to inform their species distribution model making it unclear how this may have impacted their findings and potential relevance to NC's SAV community. They also found that light availability was not a strong predictor of eelgrass distribution in their modeling, which was surprising given that light availability is a dominant factor for eelgrass. Using similar methodology, Bittner et al.[75] found that light availability was consistently an influential predictor of the distribution of five Gulf species of SAV that were modeled.

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[70] Ibid, 69
[71] Ibid, 69
[72] Ibid, 69
[73] Ibid, 69
[74] Wilson, K.L. and H.K Lotze. 2018. Climate change projections reveal range shifts of eelgrass Zostera marina in the Northwest Atlantic. Marine Ecological Progress Series. 620:47-62
[75] Bittner, R.E., E. L. Roesler, and M.A. Barnes. 2020. Using species distribution models to guide seagrass management. Estuarine, Coastal, and Shelf Science. 2020:106790

Physical Disturbances

Physical disturbances can impact SAVs and the shallow bottom habitat that they occupy by damaging or removing the plant and by changing the depth contour so that light is unable to penetrate for photosynthesis. Physical disturbance can come from fishing gear, mariculture practices, navigational dredging and impacts from marina and dock siting. Mobile bottom-disturbing fishing gear is towed or run by power, and includes bottom trawls, oyster and crab dredges, hydraulic clam dredges, clam kicking gear, and haul seines. Most commonly used in NC is the shrimp trawl, followed by oyster and clam dredges. A legislative report to the Moratorium Steering Committee compiled a list of gears used in NC and probable habitat impacts. Trawls and dredges were found to have the greatest potential. [76]

Shearing or cutting of SAV leaves, flowers, or seeds, and uprooting of the plant are most often caused by dragging or snagging by these mobile fishing gears.[77] Shearing of above ground biomass does not always result in SAV mortality, but productivity is reduced since energy is diverted to replace damaged tissue, and the nursery and refuge functions are reduced in the absence of structure. Belowground effects, such as those from toothed dredges, heavy trawls, and boat propellers, may cause total loss of SAV, requiring months to years to recover, if at all. Excessive sedimentation from bottom disturbing fishing gear and propeller wash can bury SAV and reduce water clarity, resulting in decreased SAV growth, productivity, and survival. Qualitatively, damage to eelgrass meadows from unspecified shellfish harvest dredges was surpassed only by damage from propellers.[78]

Bottom disturbing gears can affect primary productivity through the connection of bottom and water column processes. Nutrients released into the water can increase nitrogen and phosphorus levels, stimulating phytoplankton growth and enhancing secondary productivity of herbivorous zooplankton and larger prey.[79] Increased plankton growth can reduce bottom penetrating light and extend the effects of trawling beyond episodic increases in turbidity. Eventually, the remains of plankton and other organisms will settle, adding to the food available to benthic deposit feeders. However, if large amounts of organic matter are resuspended, the increase in plankton can reduce water oxygen levels, causing hypoxia and anoxia.[80] By resuspending sediments, trawling can make inorganic and organic pollutants available in the water column.[81] Such toxins can affect productivity and accumulate in organisms through food chain interactions.

Shellfish mariculture is a growing industry in NC with 278 leases in 2018.[82] With this growth comes the concerns of how shellfish mariculture may impact SAV through use of bottom disturbing gears and by mariculture practices. Mariculture practices that may have an adverse impact on SAV include the type of

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[76] MSC (Moratorium Steering Committee). 1996. Final report of the Moratorium Steering Committee to the Joint Legislative Commission on Seafood and Aquaculture of the North Carolina General Assembly North Carolina Department of Environmental and Natural Resources. Raleigh, NC

[77] ASMFC (Atlantic States Marine Fisheries Commission). 2000. Evaluating fishing gear impacts to submerged aquatic vegetation and determining mitigation strategies

[78] Ibid, 1;
Auster, P. J., and R. W. Langton. 1999. The effects of fishing on fish habitat. Pages 150-187 *in* L. B. (ed.), editor. Fish habitat: essential fish habitat and rehabilitation, volume Symposium 22. American Fisheries Society, Bethesda, MD;
Collie, J. S., S. J. Hall, M. J. Kaiser, and I. R. Poiners. 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. Journal of Animal Ecology 69:785-798

[79] NCDMF (North Carolina Division of Marine Fisheries). 1999. Shrimp and crab trawling in North Carolina's estuarine waters. Report to NC Marine Fisheries Commission. DENR, Morehead City, NC

[80] West, T. L., W. G. A. Jr., and G. A. Skilleter. 1994. A review of the effects of fish harvesting practices on the benthos and bycatch: implication and recommendations for North Carolina. US Environmental Protection Agency and NCDEHNR, Raleigh, NC;
Paerl, H. W., J. L. Pinckney, J. M. Fear, and B. L. Peierls. 1998. Ecosystem responses to internal and watershed organic matter loading: consequences for hypoxia in the eutrophying Neuse river estuary, North Carolina, USA. Marine Ecology Progress Series 166:17-25

[81] Kinnish, M. 1992. Ecology of estuaries: anthropogenic effects. CRC Press, Boca Raton, Fl; Ibid, 70

[82] Fodrie, J., C. Peterson, C.Voss, and C. Baillie, C. 2018. North Carolina strategic plan for shellfish mariculture: a vision to 2030. North Carolina Policy Collaboratory. University of North Carolina-Chapel Hill. 177 pp

farming method used (bottom or off-bottom), extent of shading, density of SAV within and adjacent to the lease area, density of product and equipment within the lease, water depth and harvest/retrieval methods.[83]

However, shellfish mariculture of bivalves such as oysters may have positive impacts to SAV by providing filtration of nitrogen and phosphorus into its shells and tissue and consuming phytoplankton and organic matter, thus improving water quality and clarity. Oysters represent a bottom-up approach to improve water quality while providing fisheries habitat and an economic benefit. Several studies are underway in NC to assess the effects of mariculture on SAV and ecosystem services. As more information becomes available, the full impacts of oyster mariculture can be determined.[84]

Other physical disturbances that can impact SAV include navigational dredging, dock and marina siting, boat wakes and prop scarring by boats and personal watercraft, and shoreline stabilization. Channel dredging impact is the physical loss of SAV within the dredge footprint. Impacts extend beyond the dredge footprint from sloughing into the channel and sedimentation coverage on nearby SAV. Impacts from marina construction to SAV come from pile jetting/driving, shoreline stabilization, excavation, installation of docks, wave attenuation, and construction of associated high ground facilities, etc. Lesser recognized impacts are indirect and come from associated boating activities. The impacts from individual docks are less than those from marinas, yet the number of such dock permits far exceeds those of marinas. If properly designed, individual piers may not pose significant threats to beds of SAV. Other impacts come from associated boating activities. Direct physical impacts from propeller scarring, vessel wakes, and mooring scars have been identified nationally as a major and growing source of SAV loss.[85]

Propeller scarring of SAV occurs when outboard vessels travel through water that is shallower than the draft of the boat. The propeller blade cuts leaves, roots, and stems, as well as creating a narrow trench, or scar, through sediment.[86] Large holes may also be blown where boaters rapidly power off shallow bottom.[87] Mechanical disturbance to the sediment damages plant rhizomes, which reduces abundance and cover for extensive periods of time. Recovery of SAV can take from two to 10 years, depending on species and local conditions. In some cases, though, the habitat may never recover.[88] Once started, SAV damage can increase beyond the initial footprint of the scar, due to scour, storms, or biological disturbance such as crab and ray burrowing.[89] Where prop scarring is extensive and SAV beds

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[83] NCDMF (North Carolina Division of Marine Fisheries). 2017. North Carolina oyster fishery management plan amendment 4. NCDMF, Morehead City, NC
[84] Carlozo, N. 2014. Integrating water quality and coastal resources into marine spatial planning in the Chesapeake and Atlantic coastal bays. MD Department of Natural Resources Chesapeake.
[85] Sargent, F. J., T. J. Leary, D. W. Crewz, and C. R. Kruer. 1995. Scarring of Florida's seagrasses: Assessment and management options. Florida Department of Environmental Protection, St. Petersburg, FL;
Fonseca, M. S., W. J. Kenworthy, and G. W. Thayer. 1998. Guidelines for the conservation and restoration of seagrasses in the United States and adjacent waters. NOAA Coastal Ocean Office, Silver Springs, MD
[86] Ibid, 85
[87] Kenworthy, W. J., M. S. Fonseca, P. E. Whitfield, K. Hammerstrom, and A. C. Schwarzschild. 2000. A comparison of two methods for enhancing the recovery of seagrasses into propeller scars: Mechanical injection of a nutrient and growth hormone solution vs. defecation by roosting seabirds. Center for Coastal Fisheries and Habitat Research, NOAA, Beaufort, NC.
[88] Zieman, J. C. 1976. The ecological effects of physical damage from motor boats on turtle grass beds in southern Florida. Aquatic Botany 2:127-139;
ASMFC (Atlantic States Marine Fisheries Commission). 2000. Evaluating fishing gear impacts to submerged aquatic vegetation and determining mitigation strategies.
[89] Patriquin, D. G. 1975. Migration of blowouts in seagrass beds at Barbados and Carriacou West Indies and its ecological and geological applications. Aquatic Botany 1:163-189;
Townsend, E., and M. S. Fonseca. 1998. Bioturbation as a potential mechanism influencing spatial heterogeneity of North Carolina seagrass beds. Marine Ecology Progress Series 169:123-132

destabilized, the ecological value of the habitat is reduced.[90]

Shoreline stabilization can threaten SAV and SAV habitat. Vertical hard structures alter the bathymetry and hydrodynamics of the adjacent bottom, with potentially adverse effects on shallow SAV. Such structures can increase reflective wave energy, causing scouring at the toe of bulkheads, eroding adjacent shorelines, and deepening adjacent water, thus reducing or eliminating wetland vegetation and shallow subtidal habitat such as SAV.[91] Other types of shoreline stabilization, such as living shorelines, can result in covering SAV due to its larger footprint, though permitting requirements do not allow living shorelines in SAV in NC. Shoreline hardening may also prevent wetlands and shallow subtidal habitats from migrating as sea level rises, resulting in loss or conversion of habitat.

<u>SAV Pathogens</u>

The endophytic slime mold protist, *Labyrinthula zosterae,* has been identified as the causative agent of wasting disease in eelgrass; however, the triggers of these pathogenic outbreaks remain unclear. Bockelmann et al.[92] have found that traces of *L. zosterae* endophytes are omnipresent in contemporary grass beds. *L. zosterae* are detectable as black lesions on grass blades, a result of necrosis, but may also be present on apparently green healthy tissue. Historic population losses of large vertebrate grazers may have, among other consequences, increased SAV vulnerability to infection by pathogens. It was suspected, but never proven, that *Labryinthula* was the cause of the wasting disease event that devastated eelgrass populations throughout the North Atlantic between 1930 and 1933, dramatically disrupting estuarine systems.[93] Higher water temperatures apparently stressed the SAV, making them more susceptible to *Labryinthula.* Vergeer et al.[94] later confirmed a decline in the microbial defenses of SAV with increasing temperature. The primary factor enhancing microbial defenses was increasing light intensity, which is related to both water quality and self-shading.

Potential impacts in NC include reductions in fisheries resources, and large reductions in migratory waterfowl populations and loss of ecosystem services. Future research should focus on obtaining quantitative data on the prevalence and abundance of the wasting disease pathogen *L. zosterae* in eelgrass populations.

<u>Chemical Control of Aquatic Nuisance Species</u>

Aquatic nuisance species are non-native and invasive species that can cause detriment to the ecosystem. Many invasive SAVs can be transported from one system to another on boats, trailers and other equipment. Aquatic nuisance SAVs form dense beds, making swimming, fishing, and boating difficult; clogging water intake systems for municipalities and industries; and impeding water flow in drainage canals. Dense beds of Eurasian watermilfoil (*Myriophyllum spicatum*) can cause the water column to become anoxic at night, stressing fish or causing them to leave the area.[95] Although

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[90] Bell, S. S., M. O. Hall, S. Soffian, and K. Madley. 2002. Assessing the impact of boat propeller scars on fish and shrimp utilizing seagrass beds. Ecological Application 12(1):206-217; Ibid, 85

[91] Berman, M., H. Berquist, J. Herman, and K. Nunez. 2007. The Stability of Living Shorelines - An Evaluation. Center for Coastal Resources Management, Virginia Institute of Marine Science, Glouster Point, VA;
Bozek, C. M. and D. M. Burdick. 2005. Impacts of seawalls on saltmarsh plant communities in the Great Bay Estuary, New Hampshire USA. Wetlands Ecology and Management 13:553-568;
Riggs, S. R. 2001. Shoreline Erosion in North Carolina estuaries. North Carolina Sea Grant. Raleigh, NC

[92] Bockelmann, A.C., V. Tams, J. Ploog, P. R. Schubert, and T. B. H. Reusch. 2013. Quantitative PCR Reveals Strong Spatial and Temporal Variation of the Wasting Disease Pathogen, *Labyrinthula zosterae* in Northern European Eelgrass (*Zostera marina*) Beds. e62169. PLoS ONE 8(5)

[93] Steel, J. 1991. Albemarle-Pamlico Estuarine System, technical analysis of status and trends. Department of Environmental and Natural Resources, Raleigh, NC

[94] Vergeer, L. H. T., T. L. Aarts, and J. D. d. Groot. 1995. The 'wasting disease' and the effect of abiotic factors (light intensity, temperature, salinity) and infection with *Labyrinthula zosterae* on the phenolic content of *Zostera marina* shoots. Aquatic Botany 52:35-44.

[95] NCDWR (North Carolina Division of Water Resources). 1996. Economic and environmental impacts of N.C. aquatic weed infestations. North Carolina Department of Environment, Health and Natural Resources. Raleigh, NC

watermilfoil and other nuisance SAVs provide some benefits to fish and crabs, such as refuge and sediment stabilization, and can be an important component in the low salinity/freshwater SAV community of northeastern NC, they can also negatively impact natural habitat by shading or out-competing native SAV species, which may have greater value to fish.[96]

Chemical herbicides are used to suppress aggressive nuisance vegetation and should be applied using an integrated management approach. Effects of herbicides are influenced by their toxic mode of action, their method of application and either target a specific species or provide a broad spectrum of control. Registered chemicals are used to control nuisance aquatic vegetation and are highly effective when following labelling. Application rates vary based on the system and environment, and efficacy of herbicides varies based on the herbicide and formulation and the specific species being treated. Rotation of herbicides is recommended because of a growing number of cases where aquatic plants are developing resistance.[97]

DWR implements the Aquatic Weed Control Program (AWCP), which focuses primarily on non-native invasive species in freshwater lakes, ponds, and rivers. The AWCP responds to requests for assistance from local governments, public utilities, and other agencies, providing technical and financial assistance (50:50 cost share).

There are growing concerns that the control of noxious aquatic weeds by herbicides may also impact the SAVs native to NC. Overall, broader coordination is needed to address and balance the impacts and patchwork treatments of noxious aquatic weeds such as hydrilla (*Hydrilla verticillata*), alligatorweed (*Alternanthera philoxeroides*), and Eurasian watermillfoil and the protection of native SAVs. Some DMF sampling has indicated that these noxious weeds, particularly Eurasian watermilfoil, may also provide nursery habitat for various fish species such as blue crab and river herring. There are other concerns of the public wanting native SAVs removed because of disruptions in boating traffic, recreation, and aesthetics. Outreach on the value of native SAV is needed to address this negative public perception.

1.4. Discussion

In order to have more resilient SAV, especially as we experience increased coastal development and extreme rainfall and flooding associated with climate change, it has become more important than ever to address water quality. Physical disturbance from fishing gears, aquaculture, as well as impacts from toxins and pathogens also should be recognized as sources of SAV loss.

1.4.1. Reducing Nutrient Loads

Submerged Aquatic Vegetation sensitivity to increasing nutrient loads occurring in NC's estuarine system makes it a valuable bio-indicator of the health of our estuarine waters. Clean water is also a necessity for estuarine health as well as human health. Addressing these issues together will ensure the overall condition of the estuarine ecosystem that is so important to healthy fisheries, coastal resilience, and overall esthetic value of these NC resources.

<u>Clean Waters and SAV: Making the Connection (March 4, 2020) Workshop summary (APNEP 2020)</u>

In March 2020, a technical workshop, Clean Waters and SAV: Making the Connection, was held that included over seventy federal, state, and local governments, academic institutions, and nonprofit organizations to discuss the scientific links between SAV health and water quality and to discuss

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[96] Ibid, 95;
NCDMF (North Carolina Division of Marine Fisheries). 2014. November 2014 revision to amendment 1 of the estuarine striped bass fishery management plan. NDCMF, Morehead City, NC
[97] Stallings, K. D. Seth-Carley, and R.J. Richardson. 2015. Management of aquatic vegetation in the southeastern United States. DJ. Integrated Pest Management 6(1):3

strategies to improve water quality for the protection and restoration of SAV in NC coastal waters. Besides providing an opportunity for different participants to learn about the connection of water quality to SAV, it also provided information to inform this issue paper. Facilitated group discussions focused on identifying additional information needed to develop long-term SAV conservation and management strategies in NC. Through facilitated group discussions, informational needs for both high and low salinity SAV were listed and then prioritized by the workshop participants. Those needs were used to guide potential implementation actions for this issue paper. A link to the workshop summary and presentations given are located at: https://apnep.nc.gov/our-work/monitoring/submerged-aquatic-vegetation-monitoring/clean-waters-and-sav-making-connection.[98]

Proposed Strategy

Following the successful examples of Chesapeake Bay and Tampa Bay and in support of the efforts of the NCDP, NC can consider the development of a five element strategy to improve water quality and restore and protect SAV. These elements include 1) supporting efforts to improve water quality, 2) protecting and restoring SAV, 3) enhancing SAV research and monitoring, 4) improving collaboration through citizen involvement, education and outreach, and 5) addressing other contributing factors such as physical disturbance and climate change. Because of the observed links between nutrients, light limitation and SAV abundance, reducing nutrients by improving water quality is the key objective to increase SAV abundance.[99]

Support Water Quality Improvement Efforts

Water quality improvements through the implementation of standards and best management practices must be supported by data. North Carolina has large amounts of basic water quality data for estuarine waters, particularly in the tributaries and along the barrier islands, but data gaps do exist especially in open water areas of the sounds. While much of the available chlorophyll *a* and turbidity data come from the DWR's Ambient Monitoring System, other state agencies like the DMF also collect water quality parameters, such as secchi disk depth, during their routine surveys. Another large data set comes from the Neuse River estuary Modeling and Monitoring Project (ModMon) and a state ferry-based monitoring system for Pamlico Sound (FerryMon). Both are led through University of North Carolina-IMS.[100] However, another light attenuating factor that is only collected by ModMon at limited stations is CDOM. Colored dissolved organic matter is linked to river discharge and salinity, but is not nutrient related and may make areas such as the Neuse and other coastal rivers more difficult to address in terms of nutrient management. All of these data sources and others should be evaluated, standardized, and expanded where possible to support existing and future water qualtiy management actions.

Current water quality improvement efforts include DWR's work toward a nutrient criteria plan for the Albemarle Sound and Chowan River. DWR's goal is to develop a scientifically defensible criteria based primarily on the linkage between nutrient concentrations and the protection of designated uses. The NCDP SAC includes several SAV, water quality and nutrient cycling/primary production dynamics experts. The NCPD SAC and DWR are reviewing potiential endpoints and parameters such as DO, chlorophyll *a*, algal density and biovolume, light penetration, SAV, and aesthetics, etc to be included in the criteria. Ongoing work on an optical model relating chlorophyll *a* to water clarity will also be used to help inform the NCPD SAC's decisions. Considering SAV when developing plans like this, and others, such

[98] Ibid, 22
[99] Ibid, 43
[100] Ibid, 22; Ibid 15

as watershed plans, will help improve water quality by expanding areas suitable for the growth and reproduction of SAV.

Protect and restore SAV

By consulting experts from Chesapeake and Tampa bays, NC can benefit from the lessons learned from their experiences, and NC can develop a similar process of protecting and restoring SAV. Like both bay examples, establishing an SAV restoration goal and determining the light requirements for growth and reproduction for SAV across salinities will help narrow the management focus on water quality parameters such as chlorophyll *a* and nitrogen loading targets.[101] This will require a multi-step and additive process to achieve the goals set forth and are descibed below. Figure X.3 provides a conceptual framework of the process.

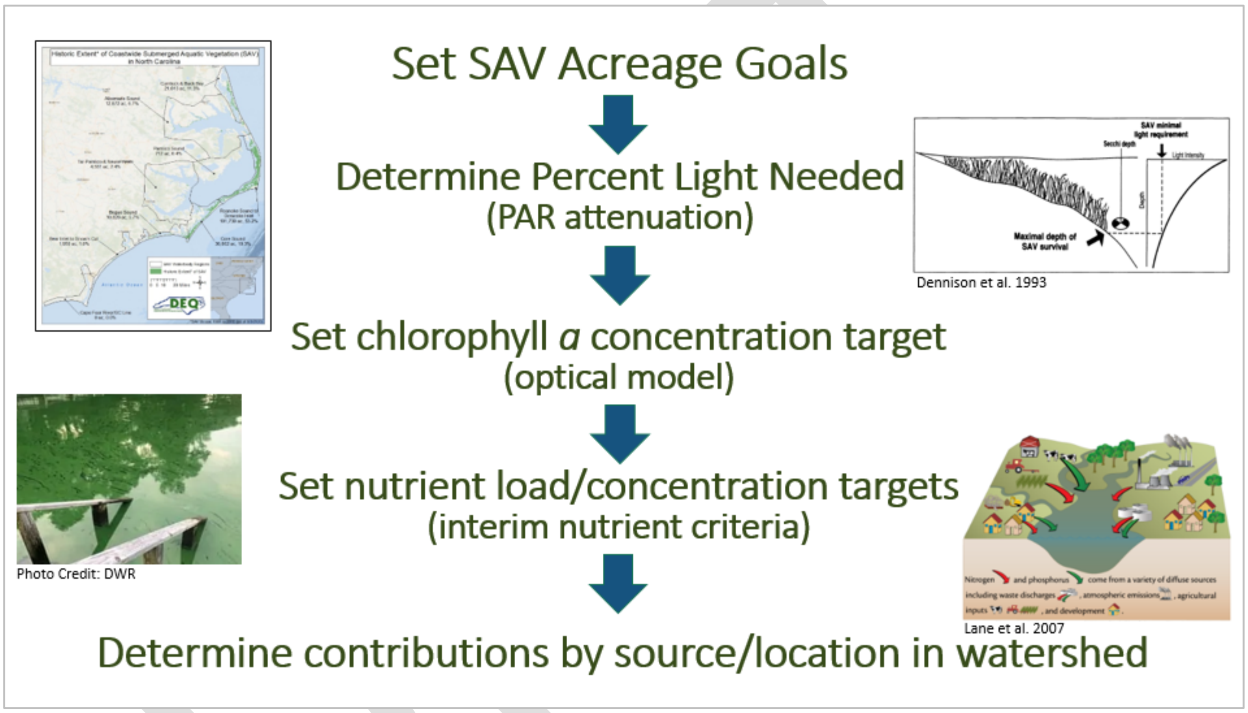

Figure X.3 Conceptual framework depicting the steps to restore SAV through water quality improvements.

Adopt an interim SAV acreage goal

As previously discussed, multiple individual mapping events have been complied to make up the historically known presence and suitable habitat of SAV along NC's coast, suggesting a historic extent of approximately 191,155 acres of SAV in public trust waters in coastal NC (Table X.1, Figure X.1 and X.2). This is currently the best known estimate of where SAV has persisted in the past, may currently persist, and will hopefully persist in the future. Therefore, the coastwide interim SAV protection and restoration goal is set at 191,155 acres. The NC coast and the known historic SAV extent is further divided into nine SAV regions to best represent waterbodies and regional variability, and are as follows: Currituck and Back Bay, Albemarle Sound, Tar-Pamlico and Neuse rivers, Pamlico Sound, Roanoke Sound to Ocracoke Inlet, Core Sound, Bogue Sound, Bear Inlet to Snow's Cut, Cape Fear River to SC line (Table X.X, Figure X.1 and X.2). These SAV waterbody regions will be beneficial to setting smart and targeted

[101] Ibid, 22

recommendations on how to obtain these acreage goals. Due to the varying methodologies, extents, resolutions, seasonality, and timeframes, etc. of the mapping events compiled to make the known historic extent of SAV in NC, the regions will allow for goals to be set coastwide and by region allowing for targeted recommended actions. The acreage goals will also be able to be informed and refined by region based on the most current and best resolution mapping events as older mapping data is re-evaluated and new mapping data becomes available.

Adopt a light target of 22% for high salinity SAV and 13% for low salinity SAV to the deep edge of the SAV beds

Water clarity and light penetration are two major limiting factors to SAV growth that can be managed with appropriate interventions. Light attenuation by non-algal particulates, phytoplankton, and CDOM therefore influence SAV growth and depth of growth.[102] In order to protect and restore SAV, studies indicate that water clarity needs to be maintained to the depth where 22% of subsurface irradiance (incident light) is available for photosynthesis for high salinity SAV and 13% subsurface irradiance for low salinity SAV.[103]

Validate a bio-optical model to define interim chlorophyll a targets for SAV waterbody regions

With funding support from APNEP, University of North Carolina-IMS scientists are validating a bio-optical model to be used to develop a chlorophyll *a* standard that will be protective of all SAV waterbody regions.[104] Results from this model can then be used to estimate chlorophyll *a* concentrations necessary to maintain water clarity needed for seagrass growth as it relates to 22% incident light to a depth of 1.7 m for high salinity SAV and 13% incident light to a depth of 1.5 m for low salinity. These concentrations can then be used as light penetration targets. For low salinity SAVs, chlorophyll *a* targets can be developed by water basins with sufficient data. This information may also help provide information for low salinity SAV areas. The Biber model was initially developed by Gallegos[105] for use in Chesapeake Bay, but Biber calibrated the model using waters from the North River. Because North River appears to have similar water clarity characteristic to the Albemarle-Pamlico system, it is likely that the model will perform satisfactorily for predicting photosynthetically available radiation (PAR) attenuation for both high and low salinity SAV areas of NC estuaries. Once the model is validated, the model will be used to develop management scenarios for chlorophyll *a* reduction to meet water clarity targets that are supportive of SAV restoration goals. Scenarios can be used to develop GIS layers of areas where there will be sufficient light for SAV persistence and may be used to determine potential growing areas that will support SAV.

Assess existing NC water quality standard for chlorophyll a for consistency with SAV growing season average for chlorophyll a supporting sufficient light penetration for SAV growth and reproduction

Once the bio-optical model is validated and calibrated with determined chlorophyll *a* targets, a comparison to existing water quality standards for class C waters of 40 ug/L concentration should be considered. This comparison will provide information on the direction and magnitude of any needed changes to the current standard to protect and restore SAV. Once comparisons are made and chlorophyll *a* targets and thresholds are adopted, a relationship between nitrogen loading and chlorophyll *a* must also be determined. Establishing this relationship quantitatively can help in managing

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[102] Kenworthy, W.J. and M.S. Fonseca. 1996. Light requirements of seagrasses *Halodule wrightii* and *Syringodium filiforme* derived from the relationship between diffuse light attenuation and maximum depth distribution. *Estuaries* 19:740–750;
Ibid, 60; Ibid, 15;
[103]Ibid, 19; Ibid, 50; Ibid 17
[104] Ibid, 15
[105] Ibid, 17

sources of nutrient loads by SAV waterbody regions and ultimately throughout coastal NC.

Enhance SAV Research and Monitoring

Understanding the distribution and health of SAV in NC is critical to understanding the dynamics of shifts in SAV species extent, distribution, and compositions. As previoulsy described, mapping of SAV has occurred at irregular intervals over the last 40+ years by several different agencies and academics, across different extents, and with varying methologies and resolutions. Traditionally, most SAV mapping has been accomplished by interpreting aerial photograpy; with the develpoment of new technology such as remote sensing by hydroacoutics and drone, and more readily available data sources such as statelite imagery, the use of the most comprenshive, highest resolution, and most cost effective methods available should be explored and used. A comprehensive monitoring and assessment program should be developed using the best available technology. This program should be developed by a team of all available partners, and should include a full-scale, routine (occurring every five years or sooner), coast-wide assessment and monitoring program. Sentinel sites should be re-evaluated and expanded along the coast, with regular ground-truthing and collections of standardized metrics (i.e. water quality, species composition, density, and condition). This will allow managers to account for changes in SAV over time, giving the ability to evaluate the success of management actions and determine causative relationships between changes in SAV species extent, distribution, and composition. Through regular monitoring and assessment, protection of this habitat can be improved and targeted, benefiting the diversity and resiliency of the entire coastal ecosystem.

Improve Collaboration

Strong collaboration among scientists, managers, and the public have been required to determine the goals and actions listed above and will be required to achieve them. Regional collaboration among resource stakeholders was also critical to success in both Chesapeake and Tampa bay. North Carolina should establish a similar collaborative process involving state agencies, local governments, academic insitutions, NGOs and the public to monitor, assess, and adaptivly manage regional and local areas. Collaboration to develop and adopt management goals, and to engage in the decision making process on needed management actions, changes, and adjustmants leads to better public understanding and appreciation of the issues. This in turn helps to change public perception and behavior. By engaging and informing stakeholders early in the process, they are more likely to play a role in implementation of management actions in their communities, such as voluntary citizen science monitoring programs.

Other Contributing Factors

Climate Change

As noted earlier, increases in extreme rainfall and flooding events associated with climate change will play a role in continued and future water quality degradation, which will result in further impacts to SAV.[106] Water quality impacts include increasing water temperatures, changes in salinities due to increased freshwater input and breaching inlets, hydrologic changes from extreme rainfall and flooding events, high loading of organic matter and organic nitrogen and phosphorus, and contaminants from agriculture and development runoff into the estuary, which in turn can fuel algal blooms and associated hypoxic events. This can be catastrophic to SAV, the other surrounding coastal habitats, and the marine organisms that use them.

It is also possible that the effects of climate change could create a shift in the distribution and metabolism of SAV species and will have impacts on the marine organisms that use SAV for nursery

[106] Ibid, 69

areas, refuge, and food supply. These same impacts will also force hundreds of fish and invertebrate species to move northward.[107] A comprehensive, routine, coastwide assessment and monitoring program would also be benfical in determing the relationships between SAV species extent, distribution, and composition and the effect of climate change. This could be instrumental in determining ways to make the NC coastal community and ecosystem more resilient.

Physical Disturbance

Submerged aquatic vegetation is offered some protections from physical disturbance under several state, federal, and interstate rules, policies and plans. Further protections and increased mitigation requirements for impacts to SAV and SAV habitat, such as restoration efforts, could be beneficial to the SAV ecosystem and add to its resiliency and the resiliency of the coastal community.

Fishing Gears

Through the authority of the MFC, the DMF implements and enforces the use of fishing gears in coastal waters. Rules describe and define habitat areas such as SAV that are protected from bottom disturbing gears. For example, the SAV along the Outer Banks are closed to trawling, mechanical clam harvest and mechanical oyster harvest. Areas known as Primary Nursery Areas (PNAs), located in the upper most tributaries of our estuarine sounds and rivers, are also closed to trawling, long haul, swipe nets, and mechanical gear for clams and oysters. Secondary Nursery Areas (SNAs) are typically located adjacent and downstream of primary nursery areas and are closed to trawls.

Through the state FMP process, SAV habitat has been protected by establishing buffers and altering boundaries to further protect SAV. Changes in trawling boundaries have occurred in Pamlico Sound, western Bogue Sound and in New River to further protect SAV. The mechanical clam harvest line in New River was also altered to protect SAV, and now both the shrimp trawl lines and the mechanical harvest lines are the same in the area below the Highway 172 Bridge. Fishing gears, practices, and areas should regularly be evaluated to ensure there are no additional impacts to SAV.

Mariculture

The growth in the NC mariculture industry may have impacts to SAV. In 2018, 69 lease applications were submitted with 39 leases granted. An average of 28 lease applications was submitted per year in the previous six years, showing a measurable increase in interest in the industry.[108] Prior to 2015, DMF, in accordance with federal regulation, did not permit shellfish leases where SAV was present. This presented numerous challenges for state managers during the application review process in determining if the location of a proposed lease complies with federal regulation of causing no or acceptably low impact to SAV. To resolve this challenge, a working group of federal and state resource agency staff was created to develop guidance for the acceptable amount of SAV during the survey by water depth. Additionally, no bottom disturbing methods can be used to harvest shellfish from leases meeting the SAV criteria. These interim conditions were later adopted as part of the 2017 authorization of the US Army Corps of Engineers Nationwide Permit (NWP 48) for Commercial Shellfish Aquaculture Activities in NC. The NWP 48 is re-evaluated and renewed in five year cycles.

Continued improvements in spatial planning and siting shellfish leases, such as the NC Shellfish Siting Tool (https://uncw.edu/benthic/sitingtool/) and the Interactive Shellfish Aquaculture Tool (https://www.arcgis.com/apps/webappviewer/index.html?id=de86f3bb9e634005b12f69a8a5947367&e

[107] Morley, J. W., R.L. Selden, R. J. Latour, T.L. Frölicher, R.J. Seagraves, and M.L. Pinsky. 2018. Projecting shifts in thermal habitat for 686 species on the North American continental shelf. PloS one, 13(5)

[108] NCCF (North Carolina Coastal Federation) 2019. State of the oyster: progress report on the oyster restoration and protection plan for North Carolina. Newport, NC

xtent=-8551979.8781%2C4121555.1994%2C-8515290.1046%2C4140072.0696%2C102100) can help provide a balance between habitat as well as social and economic considerations. Striking that balance can help facilitate sustainable development of shellfish mariculture and protection of SAV and other structural habitats, such as natural oyster rock. It can help reduce user conflicts, and provide information for scientifically based management. A recent report to the NC General Assembly provided recommendations for research needed to better understand the ecological and environmental effects of shellfish mariculture and develop standards to guide regulations and inform best management practices.[109]

Pathogens

SAV needs to be monitored on a periodic basis to assess the status of wasting disease, and its association with human-induced stresses, and to assess the health and condition of SAV. Because the highest abundance of seagrass wasting disease occurs in the summer months, the possibility of global climate change, sea level rise, and increasing rates of marine diseases, baseline data on the distribution and abundance of wasting disease are needed in order to detect trends spatially and temporally.[110] Anecdotally, another microbial stressor on SAV could be the gall-like growths on widgeon grass observed in low salinities areas such as Blounts Bay.[111] The effects of the gall-like growths on widgeon grass in Blounts Bay are unknown. However, the 2009 disappearance of widgeon grass in Blounts Bay may suggest a causal link.[112] Although outbreaks of diseases and microbial stressors are largely out of the control of coastal managers, these events need to be monitored for trends, which further supports the need for a comprehensive SAV monitoring and assessment program.

Chemical Control

A critical evaluation of ecosystem services that are provided by Eurasian watermilfoil and other invasive species may need to be considered in future management. The evaluation of organismal functional traits may provide one way to quantify the contributions of different species. These traits reflect species' tolerances to disturbance and ability to tolerate more nutrient rich waters than native SAVs, as well as their effects on primary productivity and other ecosystem functions. Invasive plants are often introduced by activities like "hitchhiking" on boats, trailers, or other equipment being moved from one location to another, being regenerated from a fragment, and being released intentionally.[113] Increasing public awareness of aquatic weeds, and aquatic invasive species in general, is paramount to a more proactive and preventative management approach. The DWR, in cooperation with WRC, has posted signs at over one hundred public boating access areas, intending to educate boaters and encourage them to clean and dry their equipment prior to going to other locations.

An objective of the NCANS Plan is to increase coordination between agencies on control of aquatic nuisance species and impacts to native SAV as well as impacts to fish habitat. There is coordination between staff of DWR's aquatic weed control program and biologists in DMF's habitat enhancement section on projects that may impact native SAV resources. However, developing a more formal collaboration among the experts will only increase communication and participation with governmental agencies.

Other concerns are the use of herbicides by private waterfront landowners who are interested in the removal of SAVs, whether invasive or native, because of the impacts to aesthetics and recreational use

[109] Ibid, 82
[110] Ibid, 83; Ibid, 85
[111] C. Wilson, USACE, personal communication
[112] J. Paxon, NCDWR, personal communication
[113] R. Emens, NCDWR personal communication

of the adjacent waters. Outreach is needed to inform landowners of the importance of native SAVs, and best management practices to address invasive SAVs including processes that are currently in place to remove invasive SAVs.

1.5. Recommended Actions

1.5.1. Protection and Resotration of SAV through water quality improvements

1. By 2021, commit to protecting and restoring SAV to reach an interim goal of 191,155 acres coastwide based on the known historical extent of SAV in NC (1981-2015), with specific targets by SAV waterbody regions for the purpose of assessing and reporting progress (Table X.1, Figure X.1 and X.2).
2. By 2021, based on known SAV requirements for growth and reproduction, adopt a light penetration target of 22% to the deep edge of SAV for high salinity SAV waterbody regions (Pamlico Sound, Roanoke Sound to Ocracoke Inlet, Core Sound, Bogue Sound, Bear Inlet to Snow's Cut, and Cape Fear River to SC line) and and a light penetration target of 13% to the deep edge for low SAV waterbody regions (Currituck and Back Bay, Albemarle Sound, and Tar-Pamlico and Neuse rivers) (Table X.1, Figure X.1 and X.2).
3. By 2021, adopt scientifically based chlorophyll *a* targets for high salinity SAV waterbody regions (Pamlico Sound, Roanoke Sound to Ocracoke Inlet, Core Sound, Bogue Sound, Bear Inlet to Snow's Cut, and Cape Fear River to SC line) based on SAV requirements for growth and reproduction (Table X.1, Figure X.1 and X.2).
4. By 2021, adopt scientifically based chlorophyll *a* targets for low SAV waterbody regions (Currituck and Back Bay, Albemarle Sound, and Tar-Pamlico and Neuse rivers) based on SAV requirements for growth and reproduction (Table X.1, Figure X.1 and X.2).
5. By 2021, investigate and determine quantitative linkages between chlorophyll *a* concentrations, nutrient loads, and sources throughout the SAV waterbody regions.
6. By 20XX, through the NCPD, develop scientifically defensible nutrient criteria to protect or restore ~12,900 acres of low salinity SAV habitat in the Albemarle Sound SAV waterbody region and related designated uses, and begin adoption of nutrient criteria into water quality standards through the rule making process.
7. By 2021, work with DMS and DWR, watershed planners, and the local governments to develop watershed restoration plans that protect, restore or replicate natural hydrology through natural and nature-based solutions in order to maintain healthy SAV, good water quality, healthy fish habitats, and additional co-benefits at a local watershed level.
8. Within SAV waterbody regions, work with DWR, DEMLR, and Soil and Water Conservation to increase the use of BMPs for that region, such as stormwater wetlands, bioretention cells (rain gardens), cisterns, and permeable pavement, within five years.
9. Cultivate and organize the leadership, partnerships, and pathways that are necessary to develop progressively refined, effective and efficient strategies for protecting and restoring SAV and associated water quality.
10. Continue to protect SAV from fishing activity disturbances by participating in the development of Fisheries Management Plans (examples Bay Scallop FMP, Hard Clam FMP), and from development activity disturbances through the review of CAMA permit applications.
11. Continue to promote the protection and restoration of floodplains, wetlands, and all coastal habitats through restoration planning with consideration to climate change and community resilience.
12. Use local, state, and federal pathways to develop policies that encourage and incentivize the conservation and restoration of SAV.

13. In conjunction with the recommended actions of the **CHPP 2021 Environmental Rule Compliance to Protect Habitat** issue paper, improve enforcement of existing regulations that pertain to protecting water quality and preventing habitat loss.

1.5.2. Monitoring Needs

1. By 20XX, using the best available technologies, implement a full scale mapping and monitoring assessment program to conduct coastwide SAV mapping at regular intervals (no more than 5 yrs apart) in order to quantitatively evaluate SAV distribution and abundance in NC over time, provide scientific basis for future protection and restoration goals, and support recommended water quality actions.
2. By 20XX, establish coastwide sentinel sites with annual monitoring and reporting requirements, including species composition, biomass, and distribution to assess impacts and changes over time, providing a scientific basis for future projections of impacts including those due to climate change.
3. By 20XX, expand the DWR ambient water quality monitoring to include additional stations and water quality parameters such as CDOM, especially in Pamlico and Albemarle sounds, and integrate with other existing water quality data sources, including DMF programs and others.

1.5.3. Research Needs

1. By 20XX, acquire necessary data and develop a hydrodynamic model for Albemarle and Pamlico sounds to determine, under normal and high rainfall conditions, the loading and sources of nutrients and sediments and their effect on water quality and SAV.
2. By 20XX, obtain more accurate estuarine bathymetry data to inform future SAV protection and restoration goals.
3. Continue to investigate the impacts of agricultural practices on water quality and assess changes in land use to recommend best management practices that would benefit the water quality in the surrounding watershed (eg. broadcast use of herbicides, animal lagoons).

1.5.4. Education, Outreach, and Citizen Science

1. By 2021, develop public education and stewardship programs with social marketing campaigns to increase the public awareness of SAV and its importance as fish habitat with numerous co-benefits, and the commitment to SAV conservation.
2. Work with local governments and NGOs to develop ways to incorporate voluntary monitoring of water quality and SAV through the use of citizen groups, coalitions, river keepers, etc.
3. Incorporate SAV protection and restoration into the economic development strategy for NC.

1.5.5. Funding

1. Obtain adequate funding to implement the SAV recommended actions.

1.6. Authority

1.6.1. NC Department of Environmental Quality

<u>NC General Statues</u>

143B-279.8. Coastal Habitat Protection Plans.