Extent of Submerged Aquatic Vegetation

High-Salinity Estuarine Waters

Metric Report

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INTRODUCTION

Why Is the Extent of Submerged Aquatic Vegetation Important Within the Albemarle-Pamlico Estuarine System?

Underwater vascular plants are key components of aquatic ecosystems. They play multiple roles in keeping Albemarle-Pamlico Estuarine System (APES) waters healthy by providing habitat, food, and shelter for aquatic life; absorbing and recycling nutrients and filtering sediment; and acting as a barometer of water quality (Thayer et al. 1984). More commonly called "submerged aquatic vegetation" (SAV), these plants enrich shallow aquatic environments around the world, providing sanctuaries for mollusks, crustaceans, and finfish as well as sustenance for waterfowl (Bergstrom et al. 2006). SAV includes marine, estuarine, and riverine vascular plants that are rooted in sediment (NCDEQ 2016) and is one of five types of aquatic plants in APES waters, the others being floating aquatic vegetation, emergent aquatic vegetation, micro- and macroalgae, and blue-greens (cyanobacteria) (Bergstrom et al. 2006). 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 (NCDEQ 2016). 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 enables them to be sensitive bio-indicators of environmental health (Biber et al. 2004).

While more than 500 species of SAV inhabit the world's rivers, lakes, estuaries, and oceans (Bergstrom et al. 2006), APES and its tidal tributaries are home to about 14 common species (NCDEQ 2016). High-salinity (10-30 ppt) species, commonly referred to as seagrass include a temperate species, eelgrass (*Zostera marina*), tropical species, shoalgrass (*Halodule wrightii*) and the eurytolerant species widgeongrass (*Ruppia maritima*) and the co-occurrence of these three species is unique to North Carolina (NCDEQ 2016). Beds of SAV occur in North Carolina in subtidal water generally less than two meters deep, and occasionally in intertidal areas of sheltered estuarine and riverine waters where there is unconsolidated substrate (loose sediment), adequate light reaching the bottom, and moderate to negligible current velocities or

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wave turbulence (Thayer et al. 1984; Ferguson and Wood 1994). SAV coverage ranges from small isolated patches less than a meter in diameter to continuous meadows covering many acres (hectares or ha).

Because the distribution, abundance, and density of SAV varies seasonally and among years in response to both environmental variability and human activity, large-scale SAV changes may occur. The major threats to SAV habitat are channel dredging and water quality degradation from excessive nutrient and sediment loading, as well as the emerging threat of accelerated sea level rise, barrier island instability, increasing water temperatures and the expansion of shellfish mariculture (NCDEQ 2016). The high value of this resource through its multiple ecosystem services makes it essential that we have the ability to detect the onset of any dramatic declines or positive responses from APNEP-led and other protection and restoration activities via regular monitoring of this metric (Carpenter and Dubbs 2012).

What Does This Metric Report?

Within the APNEP region, true seagrass communities occur on the back-barrier shelves of the Outer Banks between the U.S. Highway 64 Bridge that spans the sound between Roanoke Island

and the Outer Banks, south to Ocracoke Inlet, and on the Outer Banks and mainland shores of Core, Back and Bogue Sounds. This metric reports the extent and location of those true seagrass communities by spatial cover class (continuous, patchy, none) detected via aircraft during two survey periods: 2006-2007 (Survey 1) and 2013 (Survey 2).

- Survey 1 (2006-2007)
  - May/June 2006: Aerial surveys of Bogue and Back Sounds between Barden Inlet and Bogue Inlet.
  - October 2007: Aerial surveys between Roanoke Island and Barden Inlet.
- Survey 2 (2013)
  - May 2013: Aerial surveys between Roanoke Island and Bogue Inlet.

During Survey 2, cloud cover issues rendered the acquired imagery for much of Core Sound unusable for SAV Mapping (between Ophelia Inlet and Barden Inlet at Cape Lookout), therefore extent and location measures for SAV in much of Core Sound are not included in this report.

RESULTS

What Do the Data Show?

Spatial Trends

The areal extent of seagrass from Survey 1 was 100,843 acres (40,810 ha) while that from Survey 2 was 95,157 acres (38,509 ha), a change of -5,684 acres (-2,300 ha) or -5.6% (Table 1). Comparing continuous and patchy seagrass coverage between the two surveys showed a 15,773-acre (6,383 ha) loss of continuous seagrass, but a 10,087-acre (4,082 ha) gain of patchy seagrass (Table 1). To investigate these changes in more detail, the data were subdivided in two different ways: regionally and by seven change categories. Regionally the data were subdivided into three different zones: 1) the “North Zone” from the U.S. Highway 64 Bridge at Roanoke Island to Hatteras Inlet, 2) the “Central Zone” from Hatteras Inlet to Ophelia Inlet and, 3) the “South Zone” from Barden’s Inlet at Cape Lookout to Bogue Inlet. The data were also subdivided into the categories showing all possible categorical changes in SAV: continuous to none, patchy to none, continuous to patchy, patchy both years of analysis, none to patchy, continuous both years of analysis, patchy to continuous, and none to continuous.

Table 1. Comparison of seagrass extent between the two surveys for the entire study area (acres, hectares in parentheses).

Habitat Category	Survey 1	Survey 2	Change	% Change
Continuous	46,120 (18,664)	30,347 (12,281)	-15,773 (-6,383)	-34.2
Patchy	54,723 (22,146)	64,810 (26,228)	10,087 (4,082)	18.4
Total	100,843 (40,810)	95,157 (38,509)	-5,686 (-2,301)	-5.6

NORTH ZONE

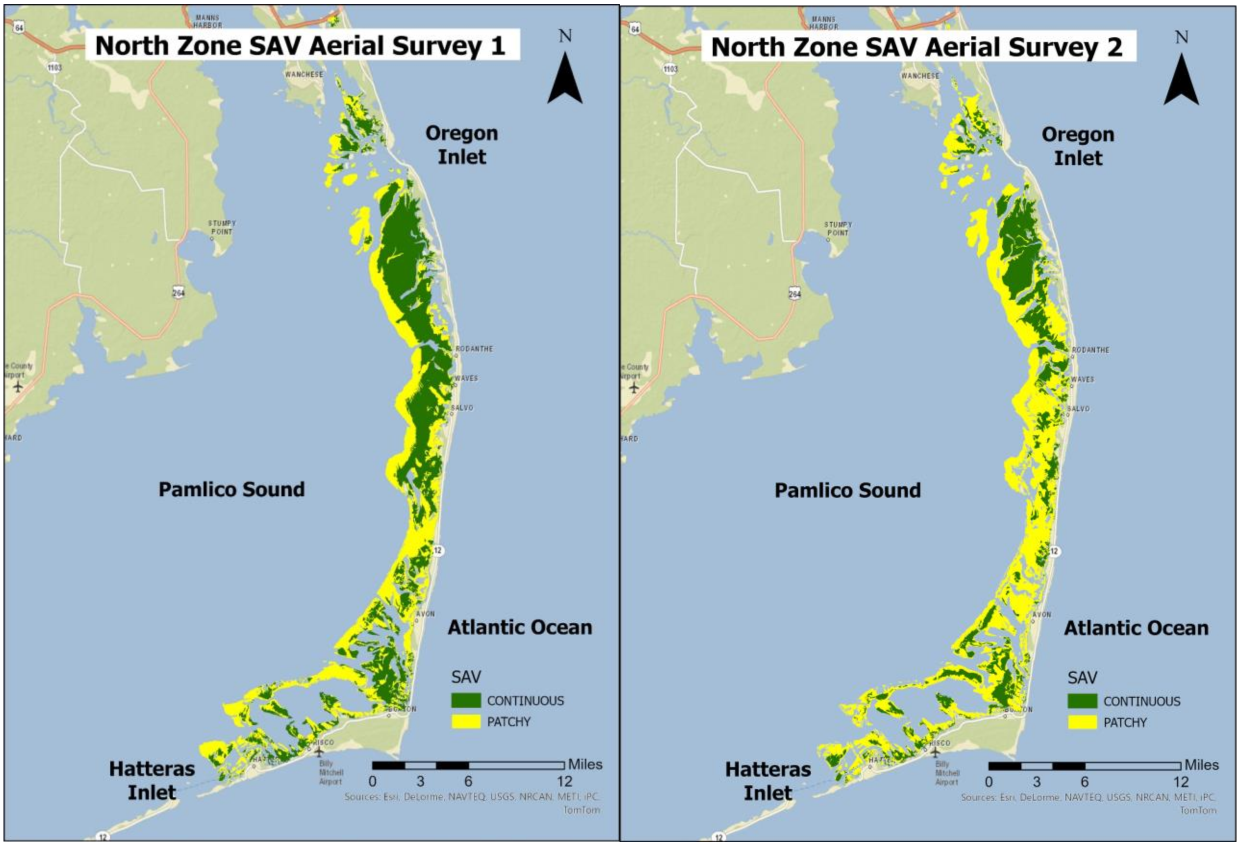

Figure 1. Seagrass location and density class in the North Zone during Survey 1 (2006-2007) and Survey 2 (2013).

The North Zone contained most of the seagrass mapped, with 70.2% of the seagrass in Survey 1 and 69.8% in Survey 2 (Figure 1). This zone also had the greatest overall seagrass habitat change of the three zones with 4,416 acres (1,787 ha) lost (-3.4%) (Table 2). There was a 20.5% loss (14,545 acres or 5,886 ha) of the continuous seagrass but a 14.3% gain (10,129 acres or 4,099 ha) of patchy seagrass.

Table 2. Comparison of seagrass extent between the two surveys for the North Zone, from the U.S. Highway 64 Bridge at Roanoke Island to Hatteras Inlet (acres, hectares in parentheses).

Habitat Category	Survey 1	Survey 2	Change	% Change
Continuous	36,356 (14,713)	21,811 (8,827)	-14,545 (-5,886)	-20.5
Patchy	34,505 (13,964)	44,634 (18,063)	10,129 (4,099)	14.3
Total	70,861 (28,676)	66,445 (26,889)	-4,416 (1,787)	-3.4

The biggest component of the overall change in the North Zone was a conversion of 15,327 acres (6,203 ha) of continuous seagrass in Survey 1 to patchy seagrass in Survey 2 (Table 3, Figure 2). The biggest habitat loss was 7,009 acres (2,837 ha) of patchy seagrass in Survey 1 that was unvegetated in Survey 2. Most of that change was located at the outer western edges of the patchy beds extending along the length of the North Zone.

Table 3. All possible classes of habitat category changes between the two mapping periods, or habitats remaining the same for the North Zone.

Habitat Category Change Class	Acres (Hectares)	% of Total SAV Area
Continuous SAV to No SAV	1,895 (767)	2.5
Patchy SAV to No SAV	7,009 (2,837)	9.4
Continuous SAV to Patchy SAV	15,327 (6,203)	20.5
Patchy SAV Both Years of Analysis	24,310 (9,838)	32.6
No SAV to Patchy SAV	4,462 (1,806)	6.0
Continuous SAV Both Years of Analysis	18,781 (7,600)	25.2
Patchy SAV to Continuous SAV	2,646 (1,071)	3.5
No SAV to Continuous SAV	203 (82)	0.3

Figure 2. Seagrass density-class changes in the North Zone from Survey 1 (2006-2007) to Survey 2 (2013).

CENTRAL ZONE

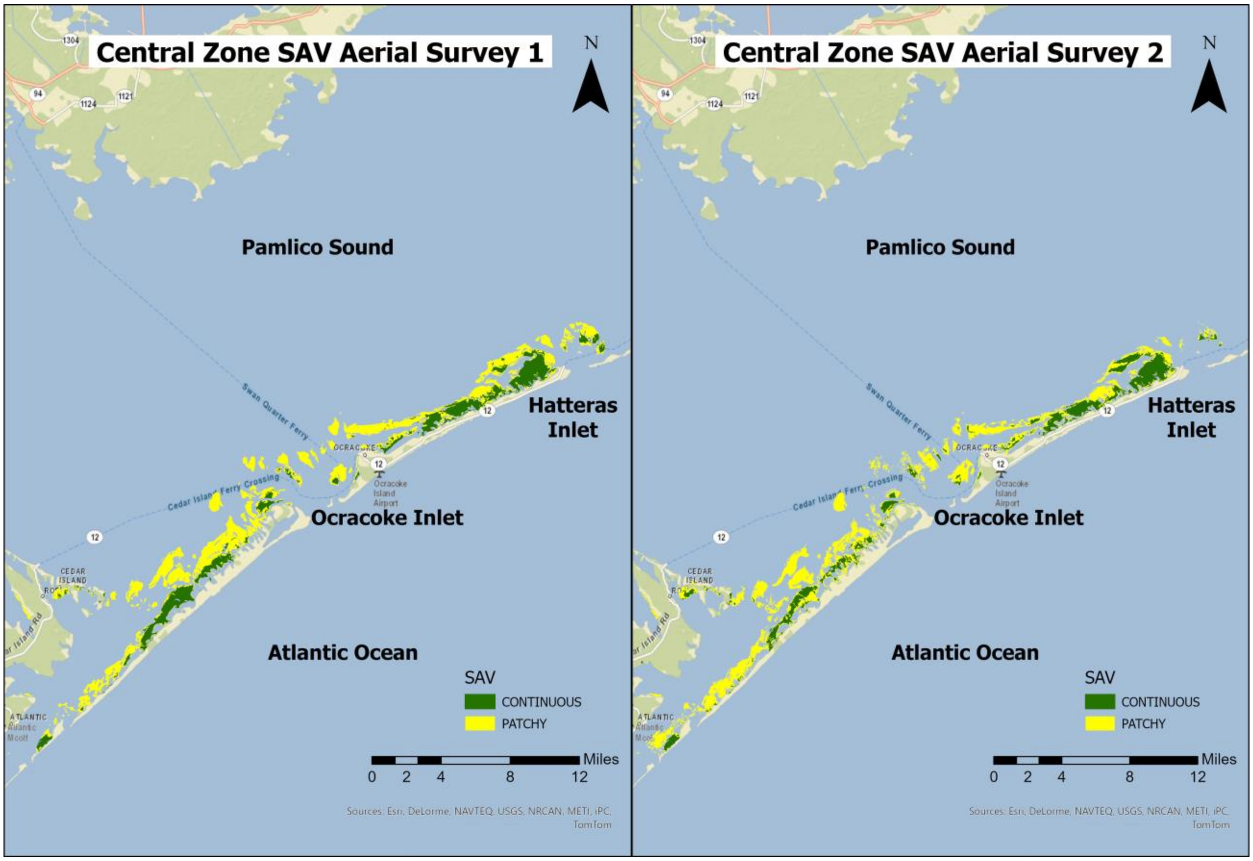

Figure 3. Seagrass location and density class in the Central Zone during Survey 1 (2006-2007) and Survey 2 (2013).

The Central Zone contained the second-most seagrass area out of the three zones with 23.9% of total seagrass area in Survey 1 and 24.7% in Survey 2 (Figure 3). Overall seagrass habitat change in the Central Zone was a 655-acre (265-ha) loss (-2.7%). Like the Northern Zone, there was a loss of continuous seagrass (896 acres or 363 ha, -3.7%) with a slight gain of patchy seagrass (241 acres or 98 ha, 1.0%) (Table 4). While the overall increase in patchy seagrass was relatively small, there was considerable conversion between patchy and continuous seagrass and unvegetated sediment (Table 5, Figure 4). While there was a change of patchy seagrass to unvegetated of 4,782 acres (1,935 ha), there was a change from unvegetated to patchy seagrass of 4,386 acres (1,775 ha). Most of the conversions between unvegetated and patchy seagrass occurred at the deep-water edge of beds or on shoals around Hatteras and Ocracoke Inlets. There was also a conversion of 1,671 acres (676 ha) of continuous seagrass to patchy seagrass.

Table 4. Comparison of seagrass extent between the two surveys for the Central Zone, from Hatteras Inlet to Ophelia Inlet (acres, hectares in parentheses).

Habitat Category	Survey 1	Survey 2	Change	% Change
Continuous	7,672 (3,105)	6,776 (2,742)	-896 (-363)	-3.7
Patchy	16,460 (6,661)	16,701 (6,759)	241 (98)	1.0
Total	24,132 (9,766)	23,477 (9,501)	-655 (-265)	-2.7

Table 5. All possible classes of habitat change, or habitats remaining the same, for the Central Zone.

Habitat Category Change Class	Acres (Hectares)	% of Total SAV Area
Continuous SAV to No SAV	401 (162)	1.4
Patchy SAV to No SAV	4,782 (1,935)	17.0
Continuous SAV to Patchy SAV	1,671 (676)	5.9
Patchy SAV Both Years of Analysis	10,186 (4,122)	36.2
No SAV to Patchy SAV	4,386 (1,775)	15.6
Continuous SAV Both Years of Analysis	5,423 (2,195)	4.0
Patchy SAV to Continuous SAV	1,112 (450)	4.0
No SAV to Continuous SAV	150 (61)	0.5

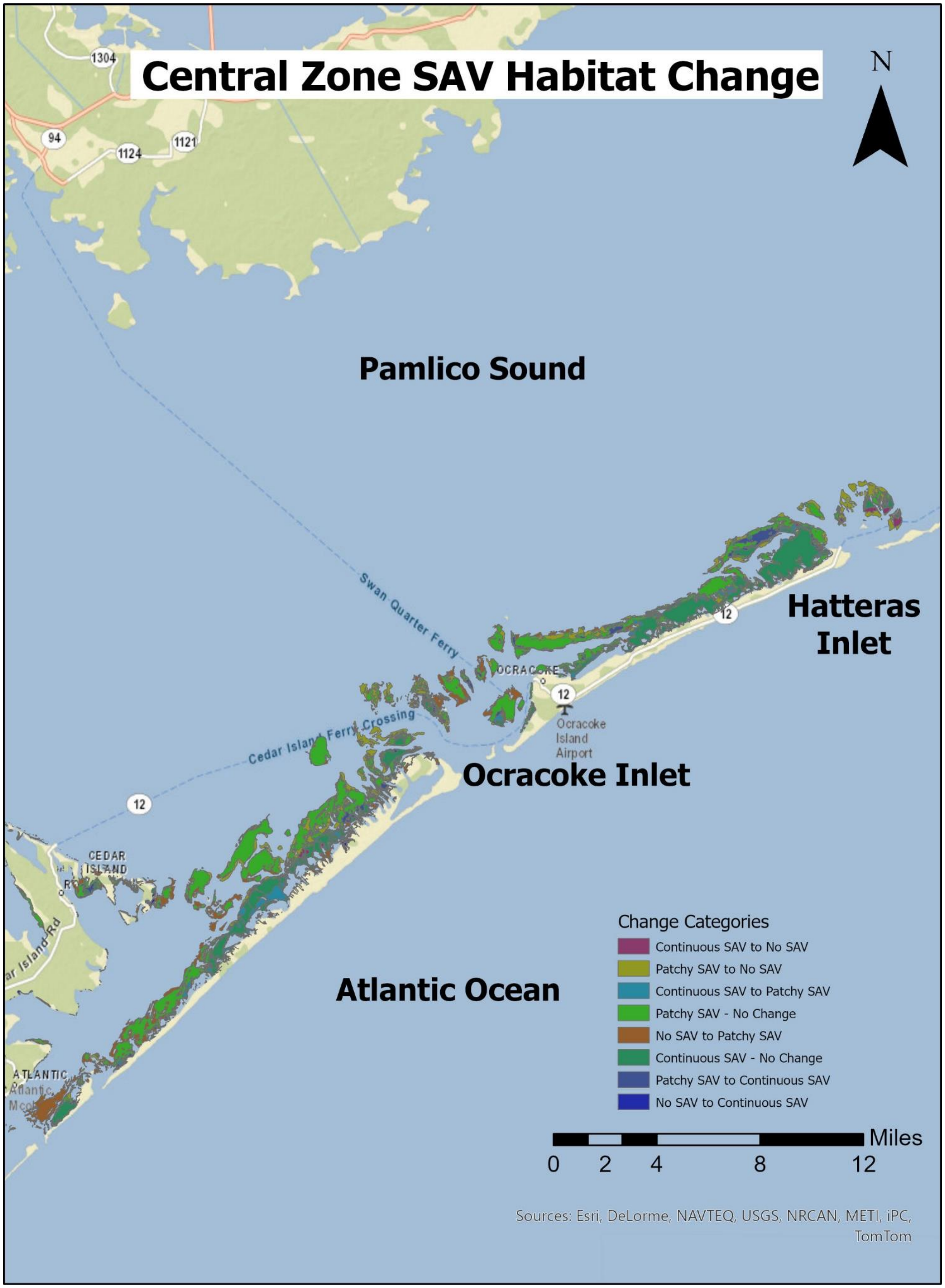

Figure 4. Seagrass density-class changes in the Central Zone from Survey 1 (2006-2007) to Survey 2 (2013).

SOUTH ZONE

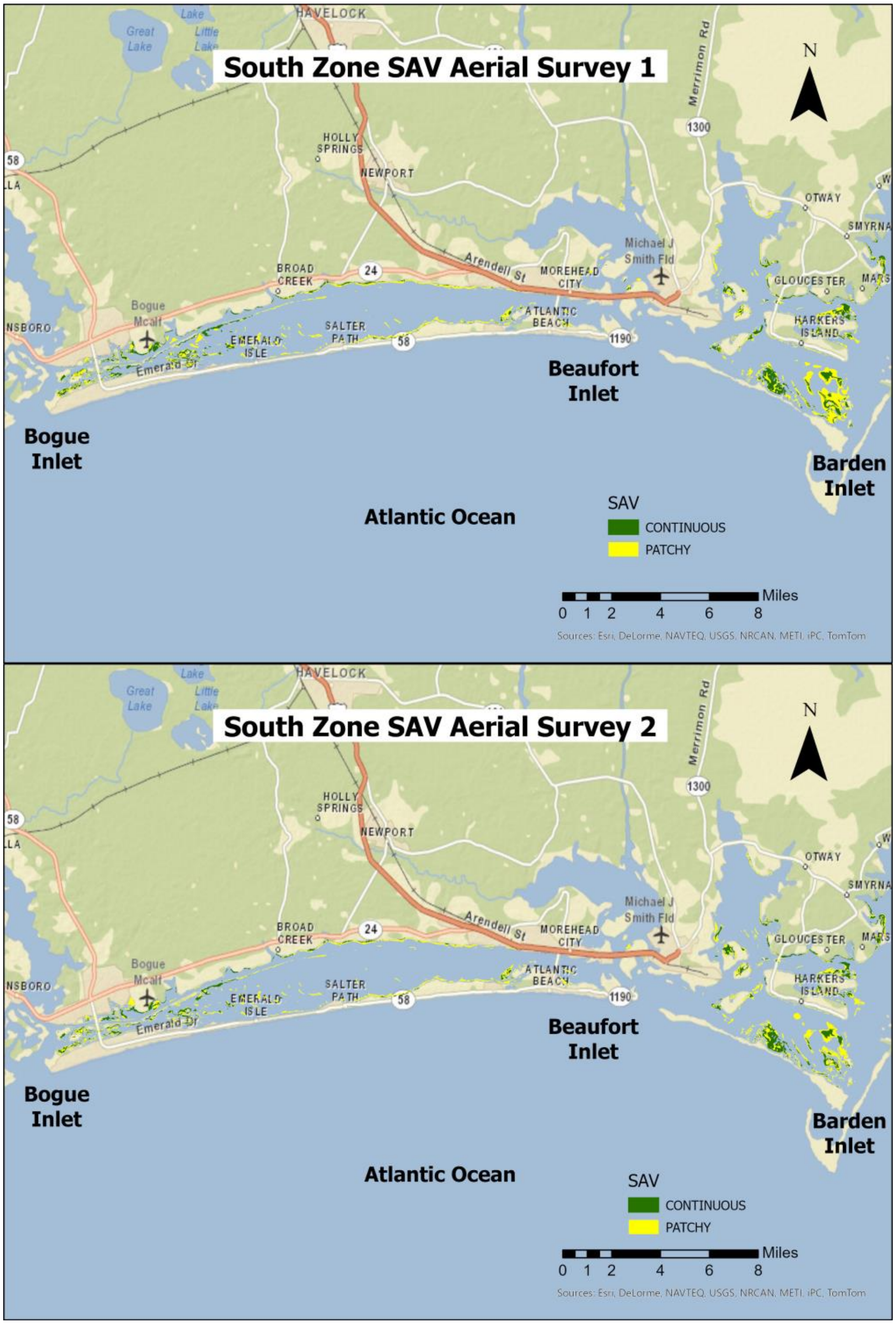

Figure 5. Seagrass location and density class in the Central Zone during Survey 1 (2006-2007) and Survey 2 (2013).

The South Zone contained the least seagrass of the three zones with 5.8% of the total seagrass area in Survey 1 and 5.5% in Survey 2 (Figure 5). Overall seagrass habitat change within this zone was a 615-acre (249-ha) loss (-10.5%). There was a loss of both continuous (332 acres or 134 ha, -5.7%) and patchy seagrass (283 acres or 115 ha, -4.8%) (Table 6). The largest conversion was 1,218 acres (493 ha) of patchy seagrass to unvegetated (Table 7, Figure 6), mostly at the deep-water edge of the beds.

Table 6. Comparison of seagrass extent between the two surveys for the South Zone, from Barden Inlet at Cape Lookout to Bogue Inlet (acres, hectares in parentheses).

Habitat Category	Survey 1	Survey 2	Change	% Change
Continuous	2,092 (847)	1,760 (712)	-332 (-134)	-5.7
Patchy	3,758 (1,521)	3,475 (1,406)	-283 (-115)	-4.8
Total	5,850 (2,367)	5,235 (2,119)	-615 (-249)	-10.5

Table 7. All possible classes of habitat change, or habitats remaining the same for the South Zone.

Habitat Category Change Classes	Acres (Hectares)	% Change
Continuous SAV to No SAV	88 (36)	1.6
Patchy SAV to No SAV	1,218 (493)	21.5
Continuous SAV to Patchy SAV	459 (186)	8.1
Patchy SAV Both Years of Analysis	1,706 (690)	30.1
No SAV to Patchy SAV	638 (258)	11.3
Continuous SAV Both Years of Analysis	1,277 (517)	22.6
Patchy SAV to Continuous SAV	216 (87)	3.8
No SAV to Continuous SAV	60 (24)	1.1

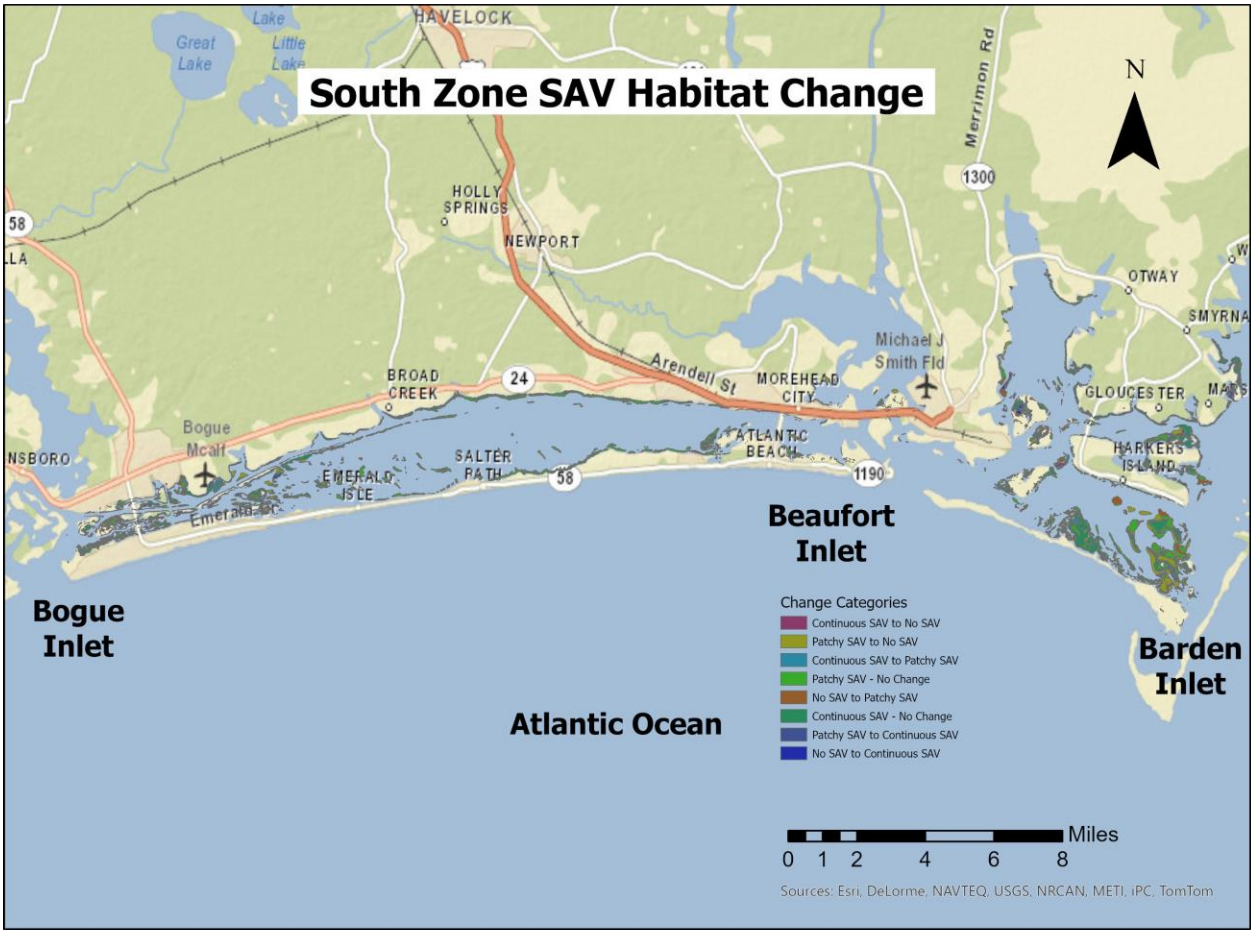

Figure 6. Seagrass density-class changes in the South Zone from Survey 1 (2006-2007) to Survey 2 (2013).

DISCUSSION

What Is Not Shown by This Metric?

The data presented here cannot be compared to earlier SAV mapping efforts. While some pre-2000 efforts to map SAV in the APNEP region have been performed, they are limited in scope and used different techniques and classification schemes.

There are at least four older sources of mapping data under review for southern Core Sound that may provide an opportunity to assess change in this important seagrass area, including 1981, 1985, 1988, and Fall 2007. Regarding more recent extent data, the entire geographic range of high-salinity SAV was flown again in June 2019. Unfortunately, the imagery from several areas was unusable for SAV mapping due to an assortment of wind, turbidity and haze issues. In response, APNEP sponsored additional flights for the entire geographic range in May and June 2020 and these data will be analyzed for the next edition of this report.

Why is This Happening?

In some areas, such as natural inlets without jetties like Ophelia and Ocracoke Inlets, observed seagrass change is primarily caused by the constant shift in shoal patterns (Cunha and Santos 2009). Another common area of change is at the deep-water edge of patchy beds, particularly for the patchy beds that run from Oregon Inlet to Cape Hatteras. In general these are the deepest portions of the beds and the areas of the meadows which are most exposed to wave energy originating from northerly wind fetches. These areas would also be the most light-limited areas of the bed and thus most vulnerable to changes in water clarity.

However, due to the natural variability in seagrass communities, change analysis based on only two dates of imagery is by definition limited in scope. There are also no regularly scheduled field monitoring or sentinel site activities for North Carolina’s seagrasses to provide the data needed to help explain the correspondence between seagrass change and the factors that may be responsible for the changes (Neckles et al. 2011). Despite this, the mapping data (Tables 1-7) and the conversion data in Table 8 provide a compelling indication of the status and trends of North Carolina’s seagrasses relative to global conditions, including other neighboring estuaries on the Atlantic seaboard. However, based on the change analysis data in Table 8, all three zones (North, Central and South) of seagrass showed net declines. Moreover, the decline in the South Zone (10.4% overall, 1.5% yr^{-1}), where there is relatively greater residential and commercial development and higher population densities, was higher than in the other two zones. While it is difficult to determine with only two dates of imagery, it appears the seagrass meadows in North Carolina may be in better condition than many others throughout the world (Waycott et al. 2009). The rates of decline are less than or equal to the global average for seagrasses since 1879 (1.5% yr^{-1}) and substantially lower than the accelerating mean global

declines reported since 1980 (5% yr^{-1}) (Waycott et al. 2009). The relatively higher rate of decline in these two waterbodies compared to the central and northern regions may be indicative of changes in environmental quality, especially nutrient and sediment loading associated with shoreline development adjacent to the sounds and in the tributary watersheds. Given the much larger land to water area ratio in Bogue and Back Sounds, as well as the expansion of shellfish closure areas, SAV and seagrasses in this region of the coast may be especially vulnerable to the impairment of water quality and other anthropogenic activities.

Table 8. From-to calculations for the net change in seagrass extent in the three North Carolina zones (acres, hectares in parentheses).

CONVERSION		**ZONE**		
From	**To**	**North**	**Central**	**South**
None	Patchy	4,462 (1,810)	4,386 (1,775)	638 (258)
None	Continuous	203 (82)	150 (601)	60 (24)
Gain		4,665 (1,888)	4,537 (1,836)	698 (283)
Continuous	None	1,895 (766)	401 (162)	88.4 (36)
Patchy	None	7,009 (2,837)	4,782 (1,935)	1,218 (493)
Loss		8,904 (3,603)	5,184 (2,098)	1,306 (528)
Net Loss (Loss – Gain)		4,239 (1,715)	647 (262)	607 (246)
Total		70,861 (28,676)	24,132 (9,766)	5,850 (2,367)
% Change		-6.0	-2.7	-10.4
% Change yr^{-1}		-1.1	-0.5	-1.5

What Are the Implications for Management?

The data indicate that even with their differences in proximity to land development and potential stressors, none of the three zones displayed increases in the extent of seagrass, despite the availability of suitable habitat for expansion of the resource. The relatively higher rate of decline in Back and Bogue Sounds (1.5% yr^{-1}) in particular should be on the radar of those responsible for ensuring the sustainability of this resource. Given the global consensus among scientists and resource managers that seagrasses are reliable indicators of water quality and environmental health, yet severely threatened by impaired environmental quality, there is an urgent need to continue to monitor this resource and integrate the status and trends of seagrass with other collaborative environmental monitoring programs in North Carolina in order to identify and manage the stressors responsible for the potential declines of seagrasses.

What are the Proposed Ultimate and Interim Targets for this Indicator?

Stakeholders within estuarine systems such as Tampa Bay, Florida derived ultimate targets with reference to historical seagrass extent provided by historical aerial images from decades past. For the limited APES waterbodies where historical aerial images of adequate quality exist to detect seagrass extent, ultimate targets could be proposed in a similar manner. However, for the majority of APES waterbodies where no such historical data archive exists, an ultimate target may be derived from other ecological criteria, such as potential seagrass habitat. Potential habitat models estimate spatial extent of SAV based on parameters such as water quality, sediment type, and wind exposure (Koch 2001).

Pending the evaluation of other ecological criteria to facilitate the support of an ultimate target, APNEP proposes a possible interim target based on Survey 1 estimates: attaining extent for continuous and patchy density classes in all three zones, thus no loss since the mid-2000s.

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APPENDIX

Data Description

All imagery was collected with Intergraph's Z/I Digital Mapping Camera (DMC) (Bands = red, green, blue, near infrared). For the Survey 1 mapping effort, images along the mainland and Outer Banks of Bogue Sound and Back Sound, and the mainland side of Core Sound north to Atlantic, North Carolina were collected on May 31 and June 1, 2006. Aircraft height was 10,000 ft (3,048 m) for a final imagery product with 1 ft (0.3 m) pixel size. All other areas in the survey area were collected on October 12, 14, and 15, 2007 with an aircraft height of 20,000 ft (6,096 m) for a final imagery product with 3.28 ft (1.0 m) pixel size.

For the Survey 2 mapping effort, all data were collected at an aircraft height of 10,000 ft (3,048 m) for a 1 ft (0.3 m) pixel size. Images along the Outer Banks of Pamlico Sound from Ocracoke Inlet to Manteo (north to Highway 64) were collected on May 30, 2013. Aircraft height was 10,000 ft (3,048 m) for a final imagery product with a 1 ft (0.3 m) size. Images along the mainland and Outer Banks of Bogue Sound and Back Sound were collected on May 27, 2013.

Data Manipulation

The imagery was loaded into ArcGIS for manual on-screen digitizing using procedures described in Rohmann and Monaco (2005). Digitizing scale was typically set to 1:1,500 except when larger homogenous areas required zooming out to a greater extent that was usually accomplished at approximately 1:6,000. Habitat boundaries were delineated around benthic habitat features (e.g., areas with visually discernable differences in color and texture patterns). The scanned images were occasionally manipulated in terms of brightness, contrast and color balance to enhance interpretability of subtle features and boundaries. This was extremely helpful, especially in deeper water where subtle boundaries or problems caused by turbidity can made features difficult to detect. The classification scheme consisted of three thematic classes: continuous seagrass, patchy seagrass and unvegetated. Continuous seagrass was defined as areas covering 70% or greater of the substrate that may contain unvegetated or sparsely vegetated areas that are smaller than the minimum mapping unit (MMU – 0.2 ha in this study). Patchy seagrass was defined as discontinuous communities covering more than 10% but less than 70% of the substrate. These areas were diffuse and irregular consisting of isolated patches that are below the MMU. Areas with less than 10% seagrass are considered beyond the level of detection of the imagery used and thus were assigned the unvegetated category.

Data Quality/Caveats

While the relative clarity and shallowness of high-salinity estuarine waters where seagrass habitat exists in the APES allow a theoretical census of seagrass habitat via high-altitude aerial surveys, there are places and conditions when the seagrass is invisible on the digital images regardless of the interpreters' skills. For example, areas of high boat traffic or localized thunderstorms can cause turbidity that can temporarily obscure seagrass beds.

There were also seasonal imagery acquisition differences that complicate the analyses. The 2007 imagery (1.0 m pixel resolution) for the North and Central Zones was acquired in September/October, while all three zones in 2013 were acquired in May/June (0.3 m pixel resolution). The South Zone was the only zone where imagery was acquired in the same season; first in May 2006 (0.3 m resolution) and next in May 2013 (0.3 m resolution). The analyses are confounded by the presence of two dominant seagrass species that have different seasonal cycles of abundance. The temperate species *Zostera marina* reaches peak abundance in spring and early summer, while the tropical species *Halodule wrightii* peaks in summer and early fall. The ideal time period to capture both species in the imagery is in early summer, but due to the poor atmospheric conditions it is very difficult to acquire imagery during the most ideal signature period. Therefore, some of the changes observed in the North and Central Zones, especially the conversions between continuous and patchy categories, could reflect the seasonal transition in the relative abundance of the two species. To address this problem and minimize the uncertainty in the change analysis above, a “net change” in seagrass extent was calculated using only the conversions between no seagrass to each of the two categories. Gains were calculated by summing the conversions from no seagrass to patchy and continuous, while losses were calculated using the sum of the conversions from the two categories to no seagrass. The difference being the net change (Table 8).

Approximately 1,000 field points were visited in Survey 1 and 800 in Survey 2. The points were randomly generated in GIS, based on areas where seagrasses were previously mapped or in water down to 2 m depth. Points were located in small craft with the aid of Differential Global Positioning Systems (DGPS) or Wide Area Augmentation System (WASS). Areas were identified visually from the boat (or wading in shallow waters) or with the aid of rakes where the bottom could not be visualized. Field points from Survey 1 were used as training data in some parts of the study area. Field points from Survey 2 did not become available in time to inform the interpretation of that image data set. The field points, from both surveys, while randomly selected were not used to perform accuracy assessments. It was determined that the use of rakes, especially near the 2 m maximum depth of seagrass occurrence often missed seagrass in obviously patchy areas, simply by raking between patches. It was also probable that rakes sometimes picked up loose seagrass with root material, drifting along the bottom, giving false positives for seagrass where none existed.

Data Availability

The data, in GIS format, can be downloaded here.

Data Gaps

Core Sound was not mapped. Due to cloud cover, imagery could not be acquired in 2013 or 2014. Therefore, Core Sound is not included in the change detection analysis.