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Improving management of a mid-Atlantic coastal barrier island through assessment of habitat condition

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ABSTRACT

To achieve desired environmental outcomes, environmental condition and trends need to be rigorously measured and communicated to resource managers, scientists, and a broader general audience. However, there is often a disconnect between responsive ecosystem monitoring and decision making for strategic long-term management. This project demonstrates how historical monitoring data can be synthesized and used for future planning and decision making, thereby closing the management feedback cycle. This study linked disparate datasets, collected for a variety of purposes and across multiple temporal and spatial scales, in order to assess and quantify current habitat conditions. The results inform integrated resource management decision-making at Assateague Island National Seashore (Maryland and Virginia, USA) by using ecological reference conditions to identify monitoring needs, areas of high vulnerability, and areas with potential for improved management. The approach also provides a framework that can be applied in the future to assess the effectiveness of these management decisions on the condition of island habitats, and is a replicable demonstration of incorporating diverse monitoring datasets into an adaptive management cycle.

1. Introduction

The use of monitoring information to assess natural resource conditions in a clear and quantifiable way can improve managers' abilities both to manage resources and to operate more effectively in legal and political discussions (Fancy et al., 2008; Carruthers et al., 2012). Environmental score cards or report cards are seen as an important tool for this type of integrated assessment, to move beyond simply identifying ecosystem change and on to applying monitoring data to ecosystem management (U.S. EPA, 2002). Careful metric selection and a strong framework to link diverse metrics, collected at different spatial and temporal scales, can help to interpret trends in natural resource condition and to elucidate connections between condition and diverse stressors. Although more general assessments have been successfully carried out at global, national, and large regional scales (Ferreira, 2000; Kiddon et al., 2003; Turner et al., 2004; IPCC, 2007; Bricker et al., 2008; Heinz Center, 2008; Williams et al., 2009), frameworks for local-level assessments have focused primarily on a few, specific resources rather than providing a holistic evaluation of site conditions.

1.1. Developing a science-based management tool at ASIS

Assateague Island, a coastal barrier island on the central east coast of the United States of America, faces a range of local and regional threats yet lacked a clearly synthesized, science-based assessment of current ecosystem conditions and trends to link monitoring to strategic management planning. This project assessed natural resource conditions of Assateague Island National Seashore (ASIS) to demonstrate how historical monitoring data can be synthesized and used for future planning and decision making.

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The objectives of this assessment were as follows:

1) To quantify and evaluate the current condition of key natural resources using a habitat-based approach, by compiling existing datasets, institutional knowledge, and observational information;
2) To establish an effective framework to synthesize available data, and to document confidence level and trends for each key natural resource. This information was then combined to describe the overall condition of each habitat and ASIS as a whole;
3) To clearly identify data gaps or needs that would allow improved assessment of overall resource condition in future assessments;
4) To develop management strategies and recommendations, and a framework for assessing the effectiveness of those management actions.

1.2. Regional setting

1.2.1. Conditions and management of Assateague Island

Assateague Island, a barrier island along the coast of Maryland and Virginia (Fig. 1A), supports a diversity of ecosystems, species, and human uses. This region is microtidal and wave-dominated, and longshore drift moves sediment in a net southward direction annually (Fisher, 1967; Krantz et al., 2009). Major storms (extra-tropical northeasters and hurricanes) play a strong role in shaping these barrier islands (Krantz et al., 2009).

Assateague Island delineates a series of coastal bays within Maryland and Virginia. The six sub-watersheds that flow into these coastal bays stretch from Delaware in the north, through Maryland, and south into Virginia, with a total area of 453 km^2 (Fig. 1A). The majority of the watershed is composed of forest (38.4%), agriculture (33.3%), and wetland (16.3%), with an increasing proportion of residential, commercial, and urban development (10.4%). The 59.5 km long island and surrounding estuarine and marine waters are protected and managed by three different government agencies. The National Park Service (NPS) manages ASIS to protect natural resources while providing for compatible recreation. The park includes most of the Maryland portion of Assateague Island, some adjacent small marsh islands, marine waters up to 0.8 km beyond the mean high water line on the Atlantic (east) side, and estuarine waters extending 0.18–1.5 km on the bay-side (west), totaling an area of 16, 381 ha (Public Law 89-195; Fig. 1A).

1.2.2. Key features of Assateague Island

Physical features: The island is naturally dynamic and structured by storm activity (Stauble et al., 1993; Krantz et al., 2009). These storms cause island over-wash with large waves resulting in sand erosion and accretion, inlet formation and closure, and the creation of new marsh platforms where overwash reaches the bay.

Ecosystem features: Globally rare sand overwash habitat provides nesting sites for the threatened shorebird, *Charadrius melodus* (piping plover) (USFWS, 1985; IUCN, 2010). The threatened and globally rare dune annual, *Amaranthus pumilus* (seabeach amaranth) (USFWS, 1993; Tyndall et al., 2000; MNHP, 2010), is only found between the high tide line and the base of the primary dune. ASIS is an important site for many migratory bird species (Dinsmore et al., 1998), and supports populations of the native white-tail deer (*Odocoileus virginianus*), as well as the historically introduced sika deer (*Cervus nippon*) and horses (*Equus caballus*) (Keiper and Keenan, 1980; Keiper, 1985). Fresh water for these species is limited; Assateague Island has an independent groundwater system, with a freshwater lens 6–7 m deep in the center of the island, and less than 1 m near both shores (Hall, 2005). The groundwater migrates slowly, generally over 50 years (Dillow and Greene, 1999).

Human use: ASIS resources are used in diverse ways by over 2 million visitors a year (ASIS, 2007). Most people visit the beach and bays for recreation, swimming, surfing, boating, fishing, clamming, birding, trail-walking, and driving along the Over Sand Vehicle (OSV) zone. The Maryland coastal bays and offshore Atlantic fisheries support important commercial fisheries, and beach and bay-side fishing is a key attraction for visitors (Murphy and Secor, 2006; ASIS, 2008). The aesthetic appeal, beach access, and unique fauna (including the feral horses) are key reasons for visiting ASIS. The park comprises one of the longest sections of undeveloped coastline on the mid-Atlantic US coast, providing a rare dark sky experience. The hunting program is an important component of management for both white-tail deer and sika deer populations (ASIS, 2010b).

1.2.3. Threats to Assateague Island resources

Threats and stressors to the natural resources of ASIS occur at three main scales: within ASIS itself (164 km^2), within the surrounding watersheds (453 km^2), and within the mid-Atlantic region (310,000 km^2), recognizing that some interactions occur between these scales.

Changes to vegetation structure and dune erosion have been observed as a result of feral horse, white-tail deer, and exotic sika deer populations (Keiper, 1985; Furbish and Albano, 1994; Seliskar, 2003; Sturm, 2007, 2008); sika deer also compete with native white-tail deer for food, and their foraging habits are changing the character of forest and shrubland at ASIS (Hall et al., 2009). Many invasive plant species occur within ASIS, including the highly invasive strain of *Phragmites australis* which changes marsh surface height and hydrology, and displaces native marsh, forming large monocultures with low habitat value for marsh inhabitants (Stalter and Lamont, 1990; Rice et al., 2000; Wilson et al., 2009). Over-sand vehicles impact the beaches and have historically impacted dune areas. Historic mosquito ditches remain (Kennish, 2001), potentially impacting wading shorebirds (Clarke et al., 1984) and estuarine water quality (Koch and Gobler, 2009).

Historic anthropogenic actions also shape the island and its ecosystems. Remnants of an artificial dune, built in the 1950's along nearly the entire length of the island to protect formerly private lands, continue to prevent the natural processes of sand overwash, and a portion (approximately 6 km alongshore) is maintained to protect infrastructure within ASIS and Assateague State Park. More significantly, Ocean City Inlet, maintained since 1934 by 700 m long jetties that extend up to 400 m into the ocean, has changed the character of the coastal bays by increasing the salinity and oceanic flushing of the bay waters; it has also disrupted longshore transport of sediment along the island, resulting in sediment deprivation and therefore accelerated erosion at the northern end of Assateague Island (Krantz et al., 2009). This deprivation is being mitigated by a long-term project to deliver sediment into the ASIS nearshore to restore the natural pre-inlet alongshore transport rate of 144,000 $m^3\ yr^{-1}$ (Schupp et al., 2007). The coastal bays within and adjacent to ASIS are impacted by development (Boynton et al., 1996; Hall et al., 2009), agriculture (Fertig et al., 2009), and concentrated animal feeding operations (Beaulac and Reckhow, 1982; Mallin and Cahoon, 2003) throughout the adjoining watersheds, and are showing evidence of degrading water quality and loss of seagrass meadows (Wazniak et al., 2007).

The mid-Atlantic region includes some of the highest population densities in North America, resulting in regional scale stressors, such as poor air quality. The mid-Atlantic region has also experienced almost twice the global mean rate of relative sea level rise over the past century (3–4 mm yr^{-1}), which is predicted to increase a further 19 cm by 2030, resulting in increased coastal flooding and changes to coastal geomorphological processes (Najjar et al., 2000). Sixty percent of the ASIS shoreline has been assessed as having high to very high vulnerability to climate change (Pendleton et al., 2004).

2. Assessment methods

A habitat framework was used to assess the natural resource condition of ASIS. Recognizing that many ecological classification systems exist, many of which are based on vegetation communities (Anderson et al., 1998; Grossman et al., 1998) or land cover (Anderson et al., 1976), the International Union for Conservation of Nature habitat classification system (IUCN, 2010) was used to provide a foundation for the delineation of habitats in this assessment (Appendix B).

Habitats were delineated using the 1993 Vegetation Classification of the Maryland portion of Assateague Island National Seashore and the 1995 Vegetation Classification of the Virginia portion (ASIS, 2010a). These GIS layers were derived from aerial photography and represented a single probable vegetation alliance within each polygon. Once a file was merged to comprise both

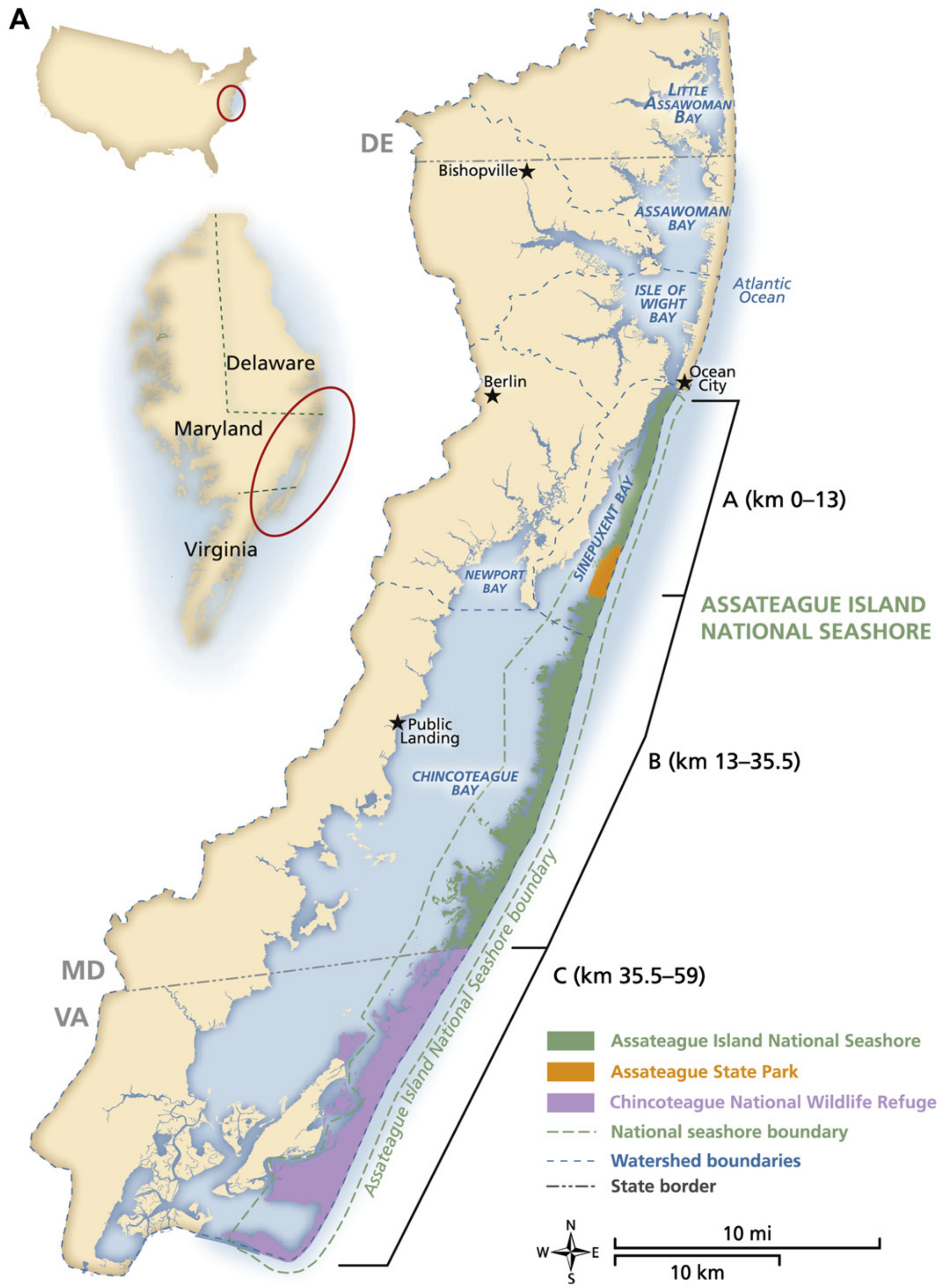


Fig. 1. A) Assateague island is a barrier island along the coast of Virginia and Maryland. The island is largely undeveloped, but development in multiple watersheds influences the coastal bays estuary. B) Seven habitats were delineated based on vegetation alliances, land cover categories, and IUCN habitat classification system.

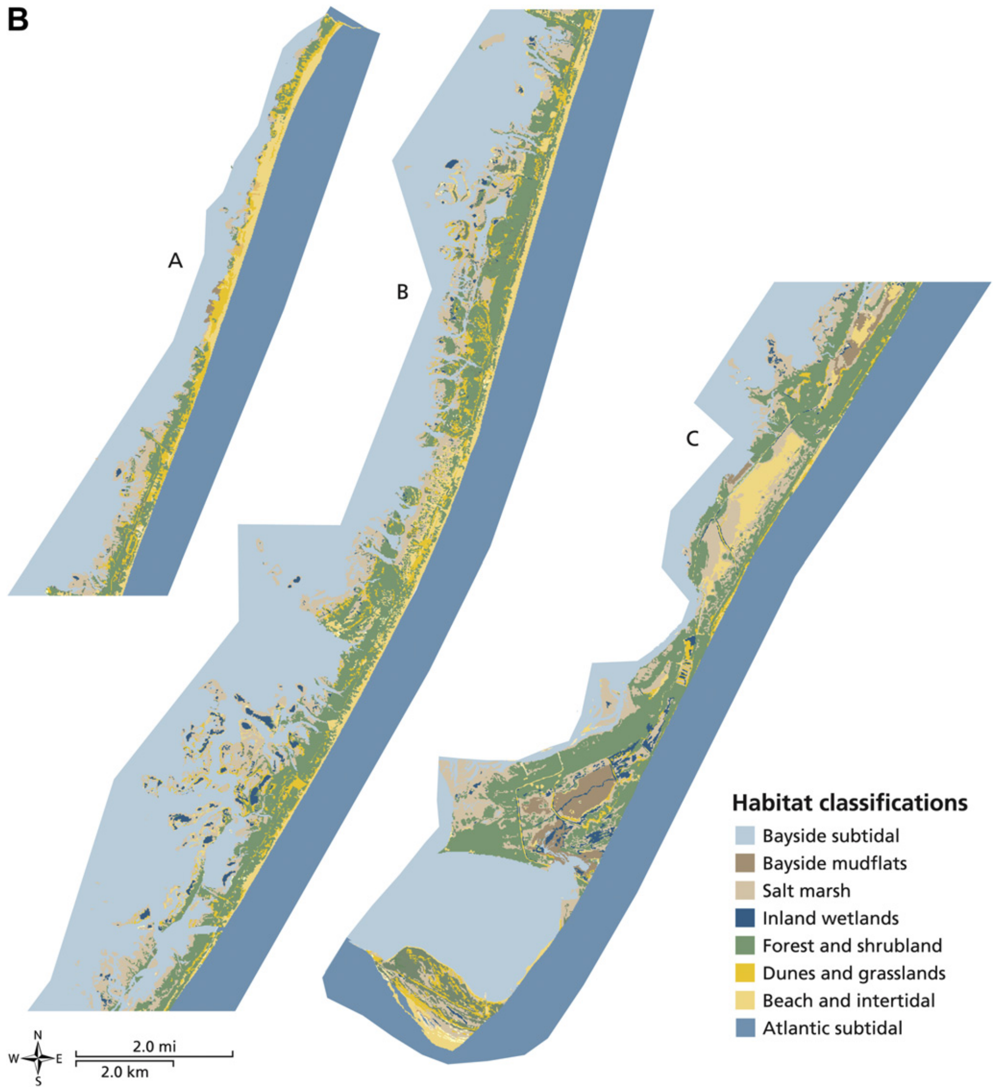


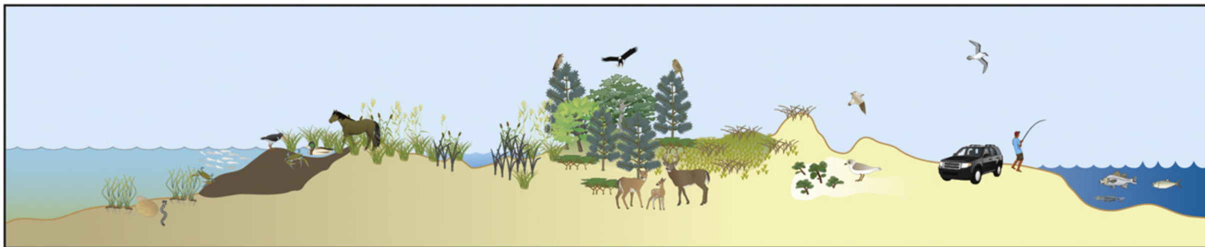
Fig. 1. (*continued*).

states, the species-specific classifications were further summarized into more general land cover categories (e.g., mixed forest, grassland). Polygons that had been delineated as containing invasive herbaceous species were merged with the adjacent land cover category. These land cover categories were then further summarized into the seven final habitat groupings (Fig. 1B and Appendix B): bayside sub-tidal and mudflats, salt marsh, inland wetlands, forest and shrubland, dunes and grassland, beach and intertidal, and Atlantic subtidal habitats (Fig. 2).

The approach taken to assess natural resource condition was to determine indicators appropriate to inform current status within each habitat (Figs. 2 and 3), establish a reference condition for each indicator, and then assess the percentage attainment of reference condition (Table 1). To present the current status in context, a conceptual framework of desired and degraded condition of each habitat was developed, based on the series of indicators identified as informing current condition within each habitat (Fig. 3). Where ideal metrics were identified that currently had no data available, they were included but grayed out to indicate an identified data gap (Fig. 3). The number of sample sites, date, and spatial range of sampling data was summarized to inform confidence in condition assessment for each indicator, and trends were indicated as either statistically significant or qualitative (Table 1). (For detailed background on included indicators, methods of calculation and data synthesis, justification of reference condition and percentage attainment, and discussion of condition and trend on a metric-by-metric basis, see Appendix A). Once attainment was calculated for each indicator, an unweighted mean was calculated to determine the condition for each habitat and then further combined to calculate an overall park assessment (Fig. 4). The researchers then met with the park's natural resource managers to provide results, discuss implications for park resources and management, and collaboratively develop management recommendations and identify research needs based on the key findings for each of the habitats.

3. Description of Assateague habitats and resource context

The boundary of Assateague Island National Seashore contains a diverse array of terrestrial and aquatic habitats (Figs. 2 and 3). Sub-tidal habitat makes up approximately 64% of the total area (20,391 ha of terrestrial and aquatic habitat combined) within the ASIS boundary, with 6402 ha on the Atlantic shore and 6628 ha within Chincoteague and Sinepuxent Bays. Of the 7361 ha of



	Bay subtidal & mudflats		Salt marsh	Inland wetlands	Forest & shrubland	Dunes & grassland	Beach & intertidal	Atlantic subtidal
	Bay subtidal	Bay mudflats						
Area (ha)	6,628.0	215.1	2,120.0	224.6	2,930.0	909.4	962.1	6,402.0
% Total Land	--	--	29.7	3.1	41.0	12.7	13.5	--
							Total area of Assateague Island (ha)	**20,391.2**

Fig. 2. Assateague Island contains a diverse array of terrestrial and aquatic habitats.

terrestrial and intertidal marsh habitats on Assateague Island, the most abundant habitats by land area are forest and shrubland (39.8%), and salt marsh (28.8%), followed by beach and intertidal (13.1%), and dune and grassland (12.4%) habitats. (For detailed descriptions of each habitat type, see Appendix B).

4. Habitat assessments and management recommendations

4.1. Overall seashore condition

The natural resources of Assateague Island National Seashore were assessed (with fair to high confidence) to be in fair condition overall, attaining 56% of desired reference condition (Fig. 4). The assessment of each habitat and the current conditions and trends of the metrics used to calculate them are listed below and in Table 1.

4.2. Bay subtidal and mudflat habitat

Bay subtidal and mudflat habitats of Assateague Island National Seashore were in good condition, attaining 66% of reference condition (Fig. 4). Confidence in the assessment of this habitat was high due to abundant data quantity for appropriate indicators. Water quality in Chincoteague and Sinepuxent Bays, within and adjacent to Assateague Island National Seashore, was assessed as being in good condition. However, even though current conditions are good, long-term trends indicate significant declines in water quality since the turn of the century (Wazniak et al., 2007). Nutrient inputs from septic systems may locally influence some areas, but the broad scale increases in nitrogen within the Chincoteague and Sinepuxent Bay system as a whole have been linked to high poultry production in the surrounding watershed. Atmospheric sources are also significant in these shallow lagoons with their small watersheds relative to water surface area. Benthic communities, such as seagrass and clams, have shown declines over the last decade that are linked, in part, to deteriorating water quality conditions. Maintaining or improving water quality is crucial to support these important benthic communities, as is continuing the current clam dredging ban. Monitoring of benthic communities should be continued, and it is recommended that standardized approaches be developed for monitoring other significant ecological and economic components of the ecosystem, such as estuarine fin fisheries and horseshoe crabs.

4.3. Salt marsh habitat

Salt marsh habitats of Assateague Island National Seashore were in degraded condition, attaining 35% of reference condition (Fig. 4). Confidence in the assessment of this habitat was fair, due to limited data availability. The invasive form of *Phragmites*, while present in the park and common in the region, has low coverage within park salt marsh habitats. It is recommended that actions to control existing *Phragmites* populations and monitoring to detect new infestations be continued to maintain the current low coverage. The bayside shoreline is eroding, which results not only in loss of salt marsh habitat, but also in sediment and nutrient addition to subtidal and mudflat habitats, causing habitat degradation. Bayside shoreline erosion is further accelerated by the high number of historic mosquito ditches and limitations to natural sand overwash processes due to historically constructed dunes and berms, all of which will be exacerbated by sea level rise. To improve the natural resource condition of salt marsh habitat within the park, it is therefore recommended to continue experimentally infilling mosquito ditches, assessing the ecological impacts of infilling, and removing existing barriers to natural overwash processes, which provide sediments that build new marsh platforms. Salt marshes are also impacted by overgrazing and trampling by the feral horse population, although the use of contraceptives has dramatically reduced the current size of the herd to near the desired condition. Future condition assessments of this habitat would be improved by the addition of metrics summarizing the nekton community, secretive marsh birds, sediment accretion rate, and soil salinity throughout the marsh. Monitoring of salt marsh nekton and sediment accretion is underway but has not yet developed sufficient data to enable analysis.

4.4. Forest and shrubland habitat

Forest and shrubland habitats of Assateague Island National Seashore were in degraded condition, attaining 26% of reference condition (Fig. 4). Confidence in the assessment of this habitat was fair, due to limited data availability. Within ASIS, forest and shrubland habitats have a very low proportion of impervious surface; a positive measure of habitat integrity. However, several other stressors are acting to degrade habitat conditions. A high percent cover of the invasive form of *Phragmites* is present in this habitat and it is recommended that efforts to identify, map, and control these occurrences continue, along with an assessment of

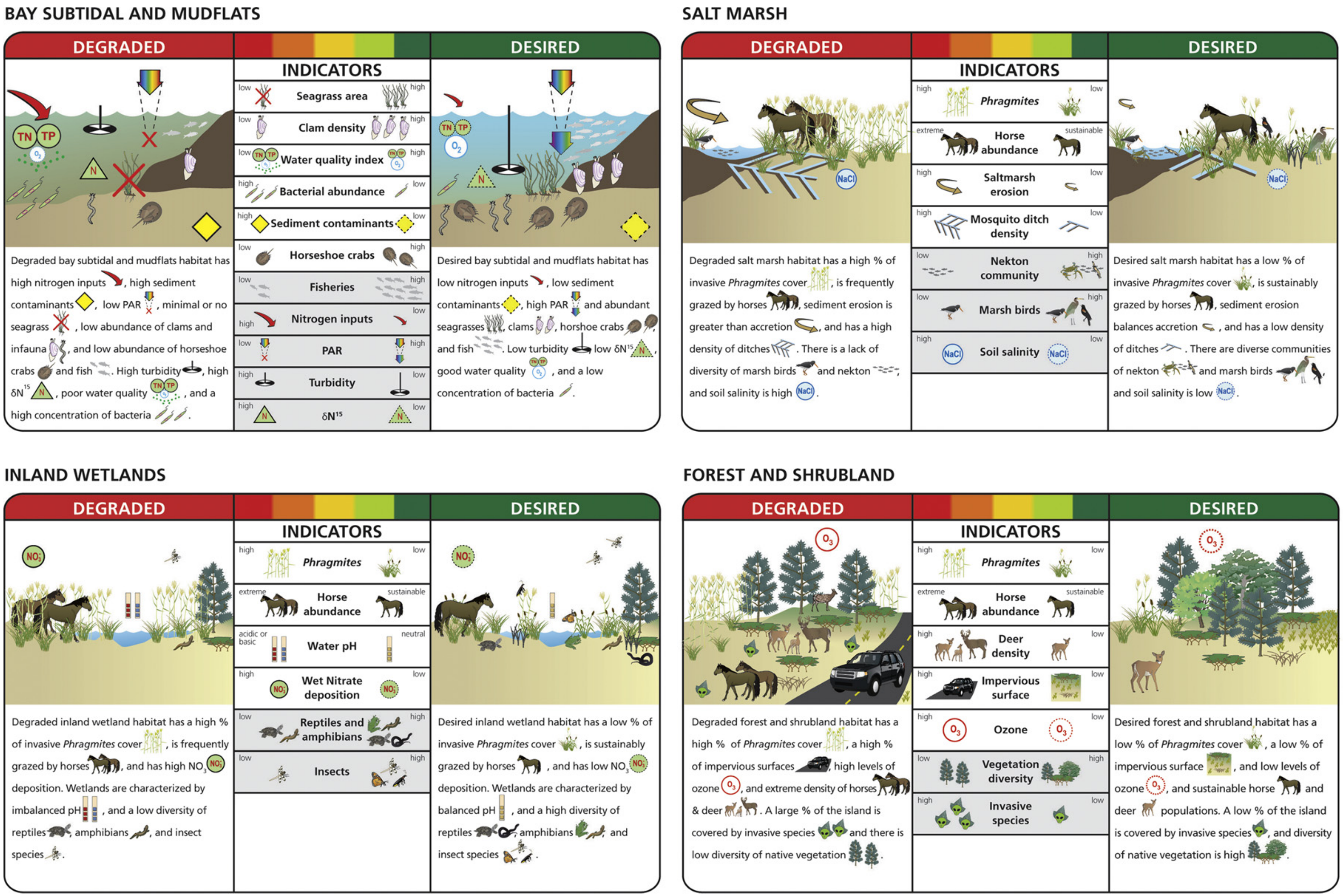


Fig. 3. Desired and degraded conditions for each habitat were identified based on the series of indicators that inform current condition within each habitat.

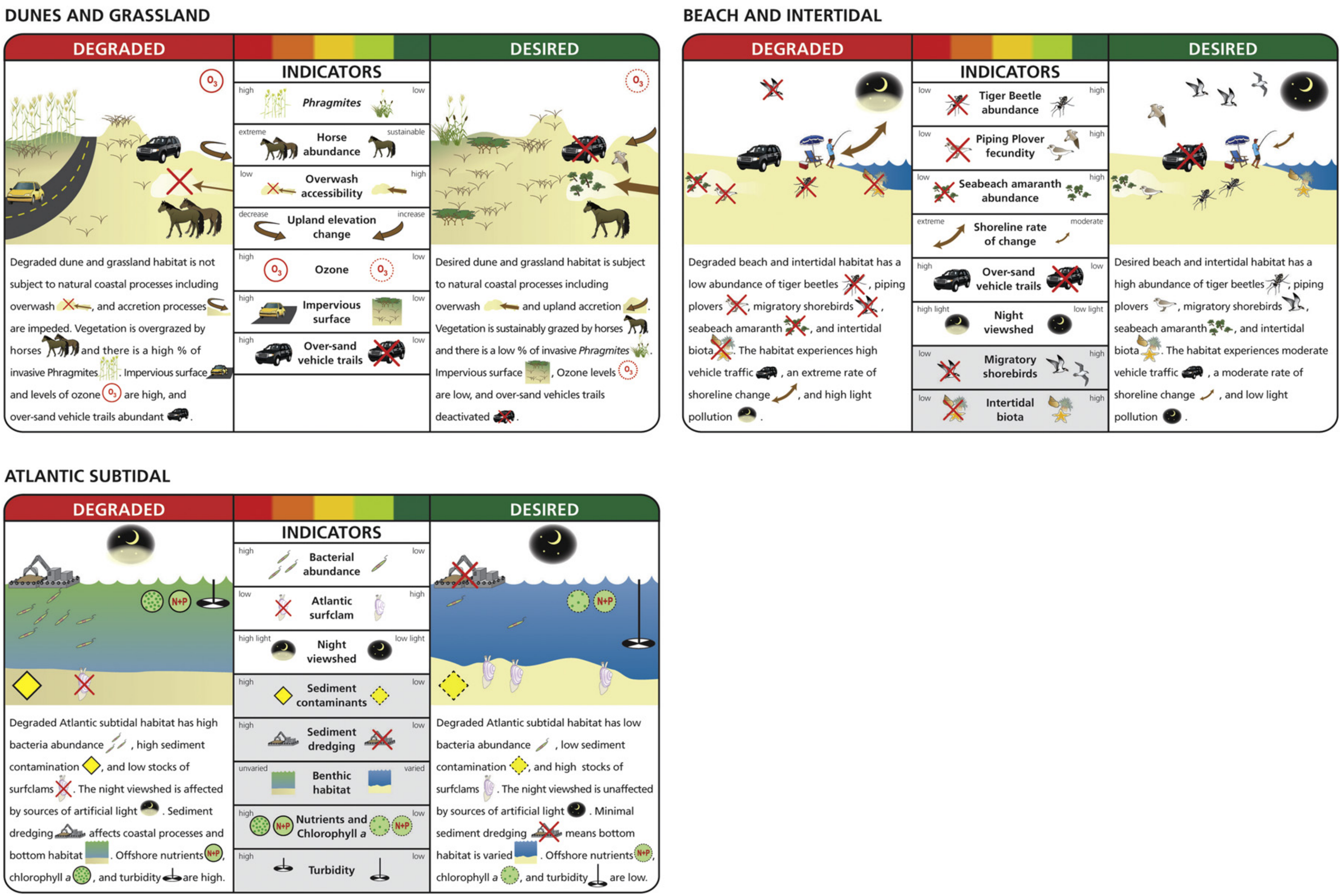


Fig. 3. (*continued*).

the ecosystem impacts of treatment using herbicides and prescribed burning. The high numbers of both horses and deer utilizing the forest and shrubland habitats result in overgrazed and trampled vegetation, and may also be influencing forest regeneration by limiting seedling establishment. This impact will be reduced by the current management goal to reduce the feral horse population to a sustainable population of 80–100 individuals. However metrics of deer herbivory impacts on indicators of plant community health combined with a deer density index are needed to fully establish management goals for the native white-tail and introduced sika deer populations. Many ozone-sensitive species are present within the forest and shrubland habitat and the periodically high ozone concentrations are contributing to the degraded condition. Limited data are currently available describing important forest resources, such as bird communities, and key ecological influences such as groundwater level and quality. Filling these data

Table 1
Assessment of each Assateague island habitat based on datasets, reference condition, attainment, current condition, and trend of each indicator.

Metric (by habitat)	Sites	Samples	Period	Reference condition	Mean value	% attainment	Current condition	Trend
Bay subtidal and mudflat habitat								
Seagrass area†	2	18	2000–2008	≥1226 ha Sinepuxent, ≥8256 ha Chincoteague	738 ha–923 ha Sinepuxent 1874–6616 ha Chincoteague	61	Good	Declining*
Clam density‡	163	163	2008	≥1.34 clams m^{-2}	0.16 clams m^{-2}	7	Very degraded	No trend
Water quality index (WQI)§	18	612	2006–2008	TN < 46 μmol; TP < 1.2 μmol; Chl *a* < 15 μg L^{-1}	TN = 33.1 μmol; TP = 1.61 μmol; Chl *a* = 6.15 μg L^{-1}	63	Good	Declining*
Bacterial abundance¶	3	3	2006	<104 MPN/100 ml	43.65 MPN	99	Very good	Unknown
Sediment contaminants‖	12	12	1993, 1996	TEL (Threshold effect level) for each of 9 metals	Multiple	77	Good	Improving*
Horseshoe Crabs**	3	10	2006–2009	No decline in yearly abundance	0.13 crabs m^{-2}	86	Very good	Unknown
Bay subtidal and mudflat overall						**66%**	**Good**	
Saltmarsh habitat								
Phragmites§	Park	1	2008	<2% area of salt marsh	1.46%	100	Very good	Improving
Horse abundance§	Park	11	2000–2010	Population of 80–100 horses	151 horses	31	Degraded	Improving*
Salt marsh erosion††	5	5	1942–1989	Stable shoreline	−0.2 m y^{-1}	0	Very degraded	Unknown
Mosquito ditch density§	Park	1	2003	All viable ditches filled	48276 m viable ditches in park	10	Very degraded	Improving
Saltmarsh overall						**35%**	**Degraded**	
Inland wetlands habitat								
Phragmites§	Park	68	2008	No ponds with *Phragmites*	12 ponds have *Phragmites*	82	Very good	Improving
Horse abundance§	Park	11	2000–2010	Population of 80–100 horses	151 horses	31	Degraded	Improving*
Water pH‡‡	11	231	2003–2004	6.5 ≤ pH ≤ 8.5	4.8 ≤ pH ≤ 8.0	54	Fair	Unknown
Wet nitrogen deposition§§	Park	1	2003–2007	<1 kg ha^{-1} yr^{-1}	4.5 kg ha^{-1} yr^{-1}	0	Very degraded	Improving*
Inland wetlands overall						**42%**	**Fair**	
Forest and shrubland habitat								
Phragmites§	Park	1	2008	< 2% area of forest and shrubland	5.9%	0	Very degraded	Improving
Horse abundance§	Park	11	2000–2010	Population of 80–100 horses	151 horses	31	Degraded	Improving*
Deer density¶¶	Park	4	2003–2006	<8deer km^{-2}	15.2	0	Very degraded	No trend
Impervious surface§,‡‡	Park	1	2004	<10%	0.15%	100	Very good	Unknown
Ozone***	Park	1	2003–2007	≤60 ppb	83 ppb	0	Very degraded	Unknown
Forest and shrubland overall						**26%**	**Degraded**	
Dunes and grassland habitat								
Phragmites§	Park	1	2008	<2% area of dunes and grassland	2.8%	0	Very degraded	Improving
Horse abundance§	Park	11	2000–2010	Population of 80–100 horses	151 horses	31	Degraded	Improving*
Overwash accessibility†††	Park	1	1993, 2003, 2004	% habitat accessible to potential overwash	79%	79	Good	Improving
Upland elevation change‡‡‡	3	6	2002, 2005, 2008	Accretion	North End: 0.57 m y^{-1} Developed Zone: 0.15 m y^{-1} OSV: 0.36 m y^{-1}	67	Good	No trend
Ozone***	Park	1	2003–2007	≤60 ppb	83 ppb	0	Very degraded	No trend
Impervious surface§,***	Park	1	2004	<10%	2.6%	100	Very good	Unknown
Over-sand vehicle trails§	Park	1	2006	% area of dunes and grassland closed to OSV use	99%	99	Very good	Improving

(*continued on next page*)

Table 1 (*continued*)

Metric (by habitat)	Sites	Samples	Period	Reference condition	Mean value	% attainment	Current condition	Trend
Dunes and grassland overall						**54%**	**Fair**	
Beach and intertidal habitat								
Tiger Beetle abundance[§§§]	44	193	2001–2009	No decrease in 2-year rolling mean	222 *Cicindela dorsalis media*, 508 *C. lepida*	44	Fair	No trend
Piping Plover fecundity[§]	Park	11	2000–2010	≥1.19 chicks per breeding pair, 5 year rolling mean	0 .4 to 1.9 chicks fledged per pair	54	Fair	No trend
Seabeach Amaranth abundance[§,***]	Park	10	2000–2009	No decrease in 3-year rolling mean	1489 plants	67	Good	Improving[*]
Shoreline rate of change[¶¶¶]	2	469	1849–2008	Within 1 SD of the 1849–1908 basal rate for Km 1–13 (-0.986 m yr^{-1})	1997–2008 average rates for North End: -0.840 m y^{-1} Below Km 13: -0.793 m y^{-1}	100	Very good	No trend
Over-sand vehicle trails[§]	Park	1	2006	% length of beach and intertidal closed to OSV use	45%	45	Fair	No trend
Night viewshed[‖‖‖]	Park	6	2009	>21.5 mag sq-arc-sec^{-2}	21.7 mag arc-sec^{-2}	100	Very good	Unknown
Beach and intertidal overall						**68%**	**Good**	
Atlantic subtidal habitat								
Bacterial abundance[¶]	8	48	2000–2006	<104 MPN/100 ml	7.8 MPN	99	Very good	No trend
Atlantic Surfclam[****]	Surveys & model	9	2000–2008	272,000 mt meat biomass and 0.15 y^{-1} fishing mortality rate	982,000 mt meat biomass, 0.02 y^{-1} mortality	100	Very good	Declining
Night viewshed[‖‖]	Park	6	2009	>21.5 mag sq-arc-sec^{-2}	21.7 mag arc-sec^{-2}	100	Very good	Unknown
Atlantic subtidal overall						**100%**	**Very good**	

Statistically significant trends are marked with *.

† Orth et al., 2008

‡ Unpublished dataset "2008 Hard Clam Survey" from Maryland Department of Natural Resources.

§ ASIS, 2010a.

¶ ASIS, 2010a.

‖ Cooper and Borjan, 2010; Zimmerman, 1996.

** Doctor and Cain, 2009.

†† Wells et al., 2003; Wells et al., 2008.

‡‡ Hall, 2005.

§§ NPS, 2010.

¶¶ Sturm, 2007.

‖‖ Unpublished dataset "2004 Land Cover" from Worcester County, Maryland.

*** NPS, 2010.

††† Morton et al., 2007.

‡‡‡ ASIS, 2010a.

§§§ Knisley, 2009.

¶¶¶ ASIS, 2010a.

‖‖‖ Unpublished data from T. Jiles, NPS Night Sky Team, 2009.

**** Northeast Fisheries Science Center, 2010.

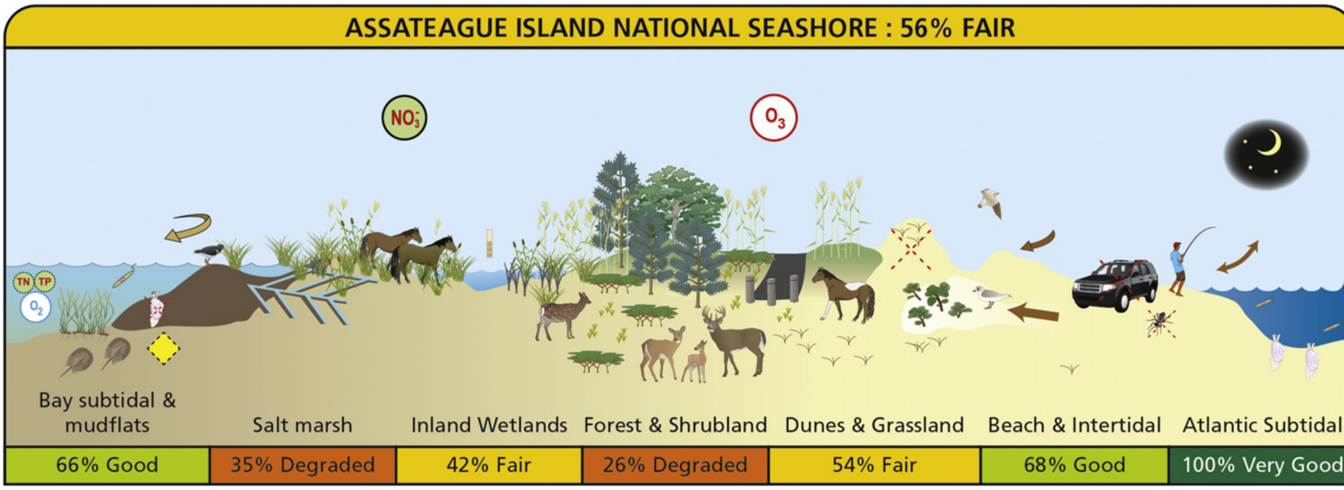
gaps would improve future assessments of resource condition for this habitat and better inform management decisions.

4.5. Inland wetlands habitat

Inland wetland habitats of Assateague Island National Seashore were in fair condition, attaining 42% of reference condition (Fig. 4). Confidence in the assessment of this habitat was limited, due to low data availability. Low abundance of the invasive form of *Phragmites* and appropriate pH indicate desirable conditions within this habitat. Poor air quality (very high wet nitrogen and sulfate deposition rates), however, has high potential to degrade sensitive wetland habitats by reducing pH and increasing nutrient concentrations. Horses also pose a threat to freshwater habitats by trampling, overgrazing, and the potential addition of nutrients. Should the ongoing horse population reduction not decrease impacts to an acceptable level, consideration should be given to limiting access to freshwater ponds showing signs of degradation. This habitat is particularly susceptible to climate change effects, especially to increased salinity resulting from sea level rise; therefore, better characterization and monitoring of salinity, groundwater conditions, and biological indicators (e.g., reptiles, amphibians, insects) would improve future condition assessments and might allow for the early identification of degradation from climate change.

4.6. Dunes and grassland habitat

Dunes and grassland habitats of Assateague Island National Seashore were in fair condition, attaining 54% of reference condition (Fig. 4). Confidence in the assessment of this habitat was high due to abundant data quantity for appropriate indicators. Low impervious surface, low number of over-sand vehicle trails, moderate to high overwash accessibility, and increases in island upland elevation are all indictors of positive natural resource conditions in dune and grassland habitat. These conditions can be maintained by continuing to control over-sand vehicle access and by reducing the extent of



Present in several habitats, invasive *Phragmites* is actively being reduced and abundant mosquito ditches are actively being filled. Rare, storm overwash habitat supports sustainable populations of the threatened beach annual, seabeach amaranth and the shorebird, piping plover. Increasingly rare, populations of tiger beetles are supported. Historically established to protect the island, artificial impediments are being removed to allow natural overwash processes. Low amounts of light pollution result in a dark night sky. Shoreline rate of change is equivalent to historic rates, as a result of active sand bypass across the ocean city inlet. Degraded air quality NO_3^- O_3 impacts vegetation and aquatic habitats. Coastal Bays water quality TN TP O_2 is currently good, but declining. Feral horse as well as native white tail, and introduced sika deer populations overgraze vegetation and trample fragile habitats.

Percent Attainment:	0-20 %	20-40 %	40-60 %	60-80 %	80-100%
Habitat Condition:	Very Degraded	Degraded	Fair	Good	Very Good

Habitat	Reference condition attainment	Current condition	Confidence in assessment
Bay subtidal and mudflats	66%	Good	High
Salt marsh	35%	Degraded	Fair
Inland wetlands	42%	Fair	Limited
Forest and shrubland	26%	Degraded	Fair
Dunes and grassland	54%	Fair	High
Beach and intertidal	68%	Good	High
Atlantic subtidal	100%	Very good	Very limited
Assateague Island National Seashore	**56%**	**Fair**	**Fair/high**

Fig. 4. The condition of each habitat, and for the park overall, was assessed based on the attainment of habitat indicators.

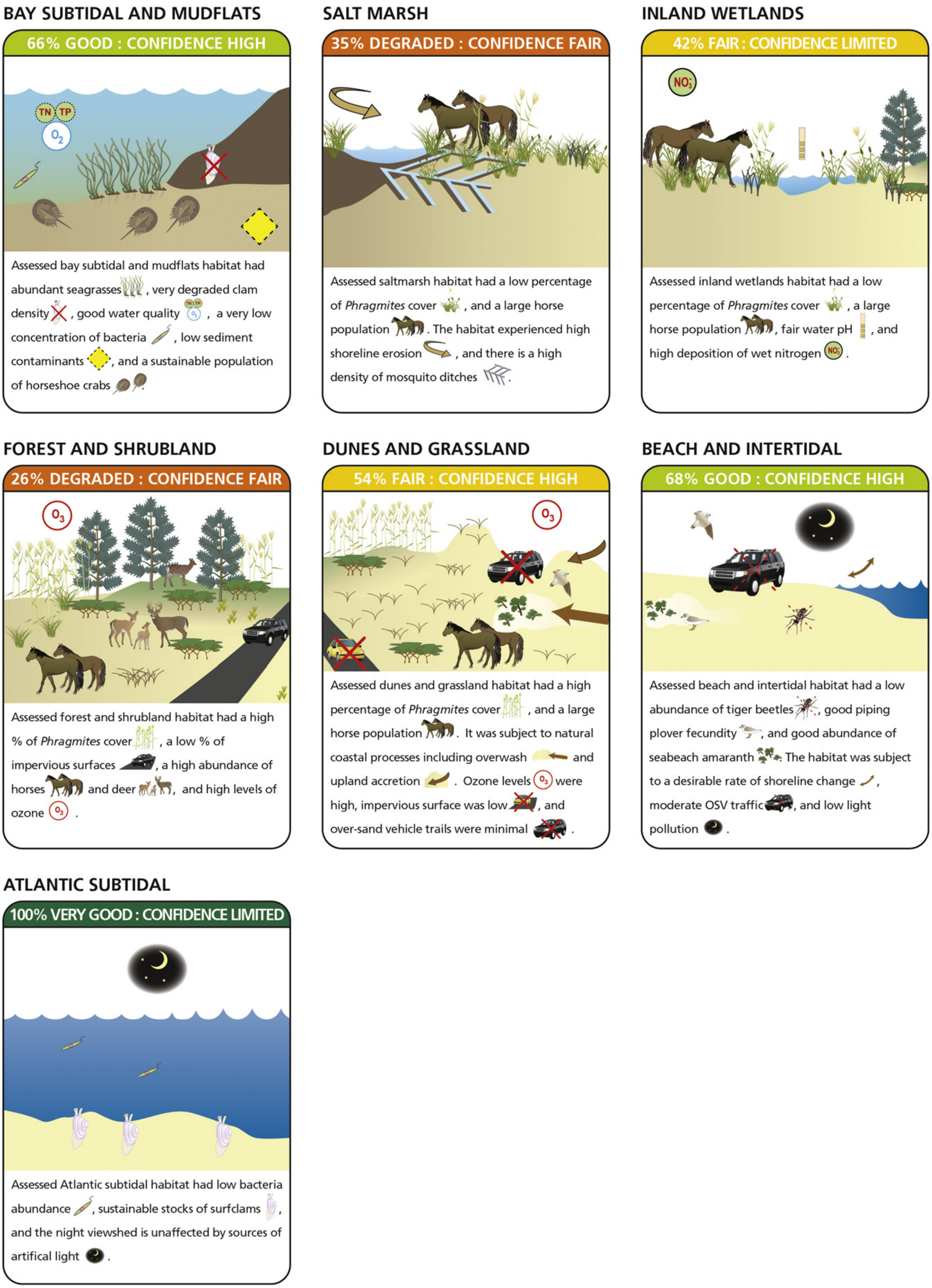


Fig. 4. (*continued*).

constructed dunes and berms to allow further ocean overwash during storms. On the negative side, a high percent cover of the invasive form of *Phragmites* is present in this habitat and it is recommended that efforts to identify, map, and control these infestations be continued, while assessing the effects of treatment. Poor air quality (high ozone) has the potential to degrade sensitive plant species in these open habitats and high horse populations pose a threat from trampling and overgrazing. Continued management to achieve a sustainable horse population is recommended.

4.7. Beach and intertidal habitat

Beach and intertidal habitats of Assateague Island National Seashore were in good condition, attaining 68% of reference condition (Fig. 4). Confidence in the assessment of this habitat was high due to abundant data quantity for appropriate indicators. Management of seabeach amaranth has been successful in increasing populations; however, further increases would be desirable to reach the U.S. Fish and Wildlife Service Recovery Plan's criteria for delisting this threatened species. Shoreline rate of change has been positively influenced by the sand-bypassing management intervention, such that rate of change is close to natural historical rates for most years. It is recommended that the mechanical sand-bypassing project be continued to maintain this essential component of sediment transport to Assateague Island. Tiger beetles have very low abundance and may be experiencing long-term decline. It is therefore recommended that as much of the shoreline as possible be maintained free of over-sand vehicle use. Piping plover populations show a sustainable fledgling rate in most years; however, their very specific habitat requirements for successful breeding (overwash-created habitats) suggest that to maintain this species as a viable population, it will be necessary to minimize artificial impediments to natural storm overwash. High horse populations also pose a threat to this habitat by overgrazing sensitive plant species such as seabeach amaranth. Future condition assessments of this habitat would be improved by including data to assess intertidal biota diversity and abundance, migratory shorebird abundance, as well as measures of recreational activity in different sections of the beach to better understand the threats to sensitive species from visitor use.

4.8. Atlantic subtidal habitat

Atlantic subtidal habitats of Assateague Island National Seashore were assessed as being in very good condition, attaining 100% of reference condition (Fig. 4). However, confidence was very limited due to a lack of appropriate indicators and baseline knowledge of this habitat. The night viewshed of Assateague Island is of high quality and increasingly rare along the eastern seaboard of the United States. Working with regional partners and municipalities to protect this resource feature is recommended. While the limited available indicators suggest that water quality and benthic fisheries are in a desirable condition, this habitat is the least known of all habitats within the park. Subsequent to benthic habitat characterization and mapping surveys currently underway, it is recommended that key indicators of habitat condition be established and monitored.

5. Conclusions

This paper successfully demonstrates how to apply a newly developed synthetic assessment framework at a local level, integrating existing data collected at multiple temporal and spatial scales at Assateague Island National Seashore, in order to assess the condition of natural resources, habitats, and the park as a whole. Overall ecosystem condition was assessed as fair, with fair to high confidence in the assessment; condition and confidence levels for each habitat varied. The key findings and management recommendations developed through this new habitat assessment framework will assist in focusing limited staff and funding resources to catalyze improvements in ecosystem health, guide restoration and monitoring efforts, and stimulate relevant research to improve future assessments of resource condition. This novel framework can additionally be applied to assess the effectiveness of ongoing and future management actions to improve or maintain habitat conditions, and demonstrates a replicable process of linking diverse monitoring data sets into an adaptive management cycle that can be applied to diverse habitats at multiple scales and different data densities.

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Appendix A and Appendix B. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ecss.2012.08.012.

References

Anderson, J.R., Hardy, E.E., Roach, J.T., Witmer, R.E., 1976. A Land Use and Land Cover Classification System for Use with Remote Sensor Data. U.S. Geological Survey, Reston, VA. Professional Paper 964.
Anderson, M., Bourgeron, P., Bryer, M.T., Crawford, R., Engelking, L., Faber-Langendoen, D., Gallyoun, M., Goodin, K., Grossman, D.H., Landaal, S., Metzler, K., Patterson, K.D., Pyne, M., Reid, M., Sneddon, L., Weakley, A.S., 1998. International Classification of Ecological Communities: Terrestrial Vegetation of the United States. In: The National Vegetation Classification System: List of Types, vol. II. The Nature Conservancy, Arlington, VA. 502.
ASIS, 2007. Visitor Survey. National Park Service Report, Assateague Island National Seashore, Berlin, MD.
ASIS, 2008. Visitor Attitudes and Experiences Associated with the Over-sand Vehicle Zone and Backcountry Camping Areas. National Park Service Report, Assateague Island National Seashore, Berlin, MD.
ASIS, 2010a. Assateague island national seashore data repository. National Park Service Natural Resource Information Portal. Online database. https://nrinfo.nps.gov/Home.mvc (accessed December 2010).
ASIS, 2010b. General hunting regulations. National Park Service, Assateague Island National Seashore. http://www.nps.gov/asis/upload/09-10%20ASIS%20Hunt%20Plan.pdf (accessed August 2010).
Beaulac, M.N., Reckhow, K.H., 1982. An examination of land use – nutrient export relationships. Water Research Bulletin 18, 1013–1024.
Boynton, W.R., Murray, L., Hagy, J.P., Stokes, C., Kemp, W.M., 1996. A comparative analysis of eutrophication patterns in a temperate coastal lagoon. Estuaries 19, 408–421.
Bricker, S.B., Longstaff, B., Dennison, W., Jones, A.B., Boicourt, K., Wicks, C., Woerner, J., 2008. Effects of nutrient enrichment in the nation's estuaries: a decade of change. Harmful Algae 8, 21–32.
Carruthers, T.J.B., Carter, S.L., Lookingbill, T.R., Florkowski, L.N., Hawkey, J.M., Dennison, W.C., 2012. A habitat-based framework for communicating natural resource condition. ISRN Ecology, 13. Article ID 384892.
Clarke, J.A., Harrington, B.A., Hruby, T., Wasserman, F.E., 1984. The effect of ditching for mosquito control on salt marsh use by birds in Rowley, Massachusetts. Journal of Field Ornithology 55 (2), 160–180.
Cooper, M., Borjan, K., 2010. Northeast Coastal and Barrier Network Assessment of Contaminant Threats – Assateague Island National Seashore. Natural Resource Technical Report NPS/NCBN/NRTR – 2010/348.
Dillow, J.J.A., Greene, E.A., 1999. Ground Water Discharge and Nitrate Loadings to the Coastal Bays of Maryland. U.S. Geological Survey Water Resources Investigations Report 99–4167, Maryland.

Dinsmore, S.J., Collazo, J.A., Walters, J.R., 1998. Seasonal numbers and distribution of shorebirds on north Carolinas' outer banks. Wilson Bulletin 110 (2), 171–181.

Doctor, S., Cain, C., 2009. Horseshoe Crab Spawning Activity in Maryland Coastal Bays: 2002–2009 (Maryland Coastal Bays Program).

Fancy, S.G., Gross, J.E., Carter, S.L., 2008. Monitoring the condition of natural resources in US national parks. Environmental Monitoring and Assessment. Electronically published May 29, 2008.

Ferreira, J.G., 2000. Development of an estuarine quality index based on key physical and biogeochemical features. Ocean and Coastal Management 43, 99–122.

Fertig, B., Carruthers, T.J.B., Dennison, W.C., Jones, A.B., Pantus, F., Longstaff, B., 2009. Oyster and macroalgae bioindicators detect elevated del-N15 in Maryland's Coastal Bays. Estuaries and Coasts 32, 773–786.

Fisher, J.J., 1967. Origin of barrier island shorelines: middle Atlantic states. Geological Society of America, Special paper 115: 66–67.

Furbish, C.E., Albano, M., 1994. Selective herbivory and plant community structure in a mid-Atlantic salt marsh. Ecology 75 (4), 1015–1022.

Grossman, D.H., Faber-Langendoen, D., Weakley, A.S., Anderson, M., Bourgeron, P., Crawford, R., Goodin, K., Landaal, S., Metzler, K., Patterson, K.D., Pyne, M., Reid, M., Sneddon, L., 1998. International Classification of Ecological Communities: Terrestrial Vegetation of the United States. In: The National Vegetation Classification System: Development, Status, and Applications, vol. I. The Nature Conservancy, Arlington, VA. 127.

Hall, M.R., Cain, C.J., Casey, J.F., Tarnowski, M.L., Wazniak, C.E., Wells, D.W., Wilson, D.E., 2009. Chapter 10: history and the future. In: Dennison, W.C., Thomas, J.E., Cain, C.J., Carruthers, T.J.B., Hall, M.R., Jesien, R.V., Wazniak, C.E., Wilson, D.E. (Eds.), Shifting Sands: Environmental and Cultural Change in Maryland's Coastal Bays. IAN Press, University of Maryland Center for Environmental Science, Cambridge, MD, pp. 149–174.

Hall, S.Z., 2005. Hydrodynamics of Freshwater Ponds on a Siliciclastic Barrier Island, Assateague Island National Seashore, Maryland. Master of Science thesis, University of Maryland Eastern Shore, Princess Anne, Maryland.

Heinz Center, 2008. The State of the Nation's Ecosystems: Measuring Land, Waters, and Living Resources of the United States. Island Press, p. 368.

IPCC, 2007. Climate change 2007: impacts, adaptation, and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E., (Eds.), Cambridge University Press, Cambridge, UK, 976pp.

IUCN, 2010. IUCN Red List of Threatened Species. Version 2010.3. downloaded on 27 September 2010. www.iucnredlist.org.

Keiper, R.R., Keenan, M.A., 1980. Nocturnal activity patterns of feral ponies. Journal of Mammology 61 (1), 116–118.

Keiper, R.R., 1985. Are sika deer responsible for the decline of white-tailed deer on Assateague Island, Maryland? Wildlife Society Bulletin 13, 144–146.

Kennish, M.J., 2001. Coastal salt marsh systems in the U.S.: a review of anthropogenic impacts. Journal of Coastal Research 17 (3), 731–748.

Kiddon, J.A., Paul, J.F., Buffum, H.W., Strobel, C.S., Hale, S.S., Cobb, D., Brown, B.S., 2003. Ecological condition of US mid-Atlantic estuaries, 1997–1998. Marine Pollution Bulletin 46, 1224–1244.

Knisely, C.B., 2009. Distribution and Abundance of Two Rare Tiger Beetles, Cicindela Dorsalis Media and C. lepida, at Assateague Island National Seashore in 2008. Internal Report. Assateague Island National Seashore, Berlin, MD, unpublished.

Koch, F., Gobler, C.J., 2009. The effects of tidal export from salt marsh ditches on estuarine water quality and plankton communities. Estuaries and Coasts 32 (2), 261–275.

Krantz, D.E., Schupp, C.A., Spaur, C.C., Thomas, J.E., Wells, D.V., 2009. Dynamic systems at the land-sea interface (Chapter 12). In: Dennison, W.C., Thomas, J.E., Cain, C.J., Carruthers, T.J.B., Hall, M.R., Jesien, R.V., Wazniak, C.E., Wilson, D.E. (Eds.), Shifting Sands: Environmental and Cultural Change in Maryland's Coastal Bays. IAN Press, University of Maryland Center for Environmental Science, Cambridge, MD, pp. 211–248.

Mallin, M.A., Cahoon, L.B., 2003. Industrialized animal production – a major source of nutrient and microbial pollution to aquatic ecosystems. Population and Environment 24 (5), 369–385.

MNHP (Maryland Natural Heritage Program), 2010. Rare, Threatened and Endangered Plants of Maryland. April 2010 ed.. Maryland Department of Natural Resources, Wildlife and Heritage Service, Annapolis, Maryland.

Morton, R.A., Bracone, J.E., Cooke, B., 2007. Geomorphology and Depositional Subenvironments of Assateague Island MD/VA. USGS Open File Report 2007-1388, online, http://pubs.usgs.gov/of/2007/1388, accessed August 2010.

Murphy, R.F., Secor, D.H., 2006. Fish and blue crab assemblage structure in a U.S. mid Atlantic coastal lagoon complex. Estuaries and Coasts 29 (6B), 1121–1131.

Najjar, R.G., Walker, H.A., Anderson, P.J., Barron, E.J., Bord, R.J., Gibson, J.R., Kennedy, V.S., Knight, C.G., Megonigal, J.P., O'Connor, R.E., Polsky, C.D., Psuty, N.P., Richards, B.A., Sorenson, L.G., Steele, E.M., Swanson, R.S., 2000. The potential impacts of climate change on the mid-Atlantic coastal region. Climate Research 14 (3), 219–233.

National Park Service, 2010. Air Quality in National Parks: Annual Performance and Progress Report. National Park Service, Department of the Interior. Natural Resource Report NPS/NRPC/ARD/NRR—2010/266.

Northeast Fisheries Science Center, 2010. 49th Northeast Regional Stock Assessment Workshop (49th SAW) Assessment Summary Report. US Department of Commerce, Northeast Fisheries Science Center Reference Document 10-01, 41 pp. National Marine Fisheries Service, Woods Hole, MA. Available online http://www.nefsc.noaa.gov/nefsc/publications/.

Orth, R.J., Wilcox, D.J., Whiting, J.R., Nagey, L.S., Owens, A., Kenne, A., 2008 Distribution of submerged aquatic vegetation in Chesapeake bay and coastal Bays. 2009. VIMS Special Scientific Report number 149. Final Report to EPA. Grant No. CB973636-01-0, http://web.vims.edu/bio/sav/sav08.

Pendleton, E.A., Williams, S.J., Thieler, E.R., 2004. Coastal Vulnerability Assessment of Assateague Island National Seashore (ASIS) to Sea-level Rise. U.S. Geological Survey, Open-File Report 2004–1020.

Rice, D., Rooth, J., Stevenson, J.C., 2000. Colonization and expansion of *Phragmites australis* in upper Chesapeake Bay tidal marshes. Wetlands 20 (2), 280–299.

Schupp, C.A., Bass, G.P., Grosskopf, W.G., 2007. Sand bypassing restores natural processes to Assateague island national seashore. In: Kraus, N.C., Rosati, J.D. (Eds.). Proceedings of Coastal Sediments '07. Reston, VA: ASCE, pp. 1340–1353.

Seliskar, D.M., 2003. The response of *Ammophila brevigulata* and *Spartina patens* (Poaceae) to grazing by feral horses on a dynamic mid-Atlantic barrier island. American Journal of Botany 90 (7), 1038–1044.

Stalter, R., Lamont, E.E., 1990. The vascular flora of Assateague island, Virginia. Bulletin of the Torrey Botanical Club 117 (1), 48–56.

Stauble, D.K., Garcia, A.W., Kraus, N.C., Grosskopf, W.G., Bass, G.P., 1993. Beach Nourishment Project Response and Design Evaluation: Ocean City, Maryland, Report 1, 1988–1992. Technical Report CERC-93-13. USACE Waterways Experiment Station, Vicksburg, Mississippi.

Sturm, M., 2007. Assessment of the Effects of Feral Horses, Sika Deer, and White-tailed Deer on Assateague Island's Forest and Shrub Habitat. Assateague Island National Seashore, National Park Service.

Sturm, M., 2008. Saving the seabeach amaranth. Park Science 25 (1), 50.

Turner, L., Tracey, D., Tilden, J., Dennison, W.C., 2004. Where River Meets Sea: Exploring Australia's Estuaries. Cooperative Research Centre for Coastal Zone, Estuary, and Waterways Management, Brisbane, p. 294.

Tyndall, R.W., Tamsey, S., Lea, C., 2000. The federally threatened *Amaranthus pumilus* Raf. (seabeach amaranth, Amaranthaceae) rediscovered on Assateague Island after 31 years. Castanea 65 (2), 165–167.

U.S. EPA, 2002. A Framework for Assessing and Reporting on Ecological Condition: an SAB Report. Environmental Protection Agency. Science Advisory Board. Washington, D.C. EPA-SAB-EPEC-02-009.

U.S. Fish and Wildlife Service, 1985. Endangered and threatened wildlife and plants; determination of endangered and threatened status for the piping plover: final Rule. Federal Register 50 (238), 50726–50734.

U.S. Fish and Wildlife Service, 1993. Endangered and threatened wildlife and plants; determination of seabeach amaranth (*Amaranthus pumilus*) to be a threatened species. Federal Register 58 (65), 18035–18042.

Wazniak, C.E., Hall, M.R., Carruthers, T.J.B., Sturgis, B., Dennison, W.C., Orth, R.J., 2007. Linking water quality to living resources in a mid-Atlantic lagoon system, USA. Ecological Applications 17 (5S), 64–78.

Wells, D.V., Hennessee, E.L., Hill, J.M., 2003. Shoreline Erosion as a Source of Sediments and Nutrients, Northern Coastal Bays, Maryland. Coastal and Estuarine Geology File Report No. 02–05): Maryland Geological Survey, Baltimore, Md., on Compact Disk (CD-ROM).

Wells, D.V., Hennessee, E.L., Hill, J.M., Van- Ryswick, S., 2008. Shoreline Erosion as a Source of Sediments and Nutrients, Southern Coastal Bays, Maryland - Phase II: Sample Analysis and Interpretation. Maryland Department of Natural Resources and National Oceanic and Atmospheric Administration. NOAA Award No. NA05NOS4191142.

Williams, M., Longstaff, B., Llanso, R., Buchanan, C., Dennison, W.C., 2009. Development and validation of a spatially-explicit index of Chesapeake Bay health. Marine Pollution Bulletin 59 (1–3), 14–25.

Wilson, D.E., Wazniak, C.E., Boward, D.M., Carruthers, T.J.B., Chalmers, R.J., Clearwater, D.H., Dennison, W.C., Hairston-Strang, A.B., Hall, M.R., Irani, F.M., Jesien, R.V., Knapp, W.M., Koch, E.W., Kyde, K.L., Luscher, A.E., Naylor, M.D., Orth, R.J., Spaur, C.C., Tarnowski, M.L., Wicks, E.C., Zimmerman, C.S., 2009. Habitats of the coastal bays and watershed. In: Dennison, W.C., Thomas, J.E., Cain, C.J., Carruthers, T.J.B., Hall, M.R., Jesien, R.V., Wazniak, C.E., Wilson, D.E. (Eds.), Shifting Sands: Environmental and Cultural Change in Maryland's Coastal Bays. IAN Press, University of Maryland Center for Environmental Science, Cambridge, MD, pp. 345–392.

Zimmerman C.S., 1996. Assateague island national Seashore an Inventory of estuarine sediments for Contaminants Final Report. Geochemical and Environmental Research Group Analytical Report (#8990032), p. 72.