2003

The Seagrasses of the Mid-Atlantic Coast of the United States

E. W. Koch

R. J. Orth
Virginia Institute of Marine Science

UNEP WCMC

World Atlas of Seagrasses

Edmund P. Green & Frederick T. Short

UNIVERSITY OF CALIFORNIA PRESS
Berkeley Los Angeles London

21 The seagrasses of THE MID-ATLANTIC COAST OF THE UNITED STATES

E.W. Koch
R.J. Orth

The mid-Atlantic region of the United States includes four states: Delaware, Maryland, Virginia and North Carolina. It is characterized by numerous estuaries and barrier-island coastal lagoons with expansive salt marshes and seagrass beds in most shallow-water areas[1]. There are no rocky shores. Hard substrates are either man-made (rock jetties and riprap or wood pilings) or biogenically generated (oyster and worm reefs). Sediments are predominantly quartz sand in shallow exposed areas with finer grain sediments in deeper or well-protected areas. Marsh peat outcroppings or cohesive sediments are sometimes found in the subtidal areas adjacent to eroding marshes. Climatic variations are large with air temperatures ranging from –10°C to 40°C and water temperatures ranging from 0°C to 30°C. Tides are equal and semi-diurnal but relatively small in range (maximum of 1.3 m during spring tides).

The largest estuary in the country, the Chesapeake Bay (18 130 km^2), occurs in this area. Its watershed covers 165 760 km^2, drains from six states and is inhabited by more than 15 million people. Additionally, the estuarine system of the state of North Carolina is the third largest in the country, encompassing more than 8 000 km^2 with a watershed of more than 63 000 km^2. Other estuaries in the mid-Atlantic include the Delaware Bay and a series of barrier-island coastal lagoons.

Flowering aquatic plants are common in the estuaries of the mid-Atlantic region. They are often referred to as submersed aquatic vegetation (SAV). This term includes all flowering aquatic plants from freshwater to marine habitats. The term "seagrass" is used exclusively for species that occur in the higher salinity zones (>10 psu)[2,3]. Only three seagrass species are found in the mid-Atlantic region: *Halodule wrightii* (shoal grass), *Ruppia maritima* (widgeon grass) and *Zostera marina* (eelgrass). The northernmost area of the mid-Atlantic (Delaware estuaries and bays) is presently unvegetated. In contrast, the middle and southern areas are colonized by monospecific stands or by intermixed beds of seagrass (usually two species). The beds can vary from small and patchy to quite extensive. The largest seagrass bed in the Chesapeake Bay is composed of a mixture of *Zostera marina* and *Ruppia maritima* and covers 13.6 km^2.

Seagrass habitat provides food and refuge from predators for a wide variety of species, some of which have recreational and commercial significance. The invertebrate production in just one seagrass bed in the lower Chesapeake Bay was estimated to be 0.4 metric tons per year[4]. Seagrass beds in Chesapeake Bay are reported to be important nursery areas for the blue crab, *Callinectes sapidus*, whose commercial harvest can yield close to 45 000 metric tons in a good year. The bay scallop (*Argopecten irradians*) fishery is also closely tied to seagrass abundance because the larval stage attaches its byssal thread to seagrass leaves. The decline of seagrasses in Virginia's coastal bays in the 1930s led to the complete disappearance of the bay scallop, and loss of a substantial commercial fishery. Seagrasses have not returned to this region, nor have bay scallops. Other important local fisheries sometimes (but not always) associated with seagrasses include hard clams (*Mercenaria mercenaria*) and fish of commercial and recreational importance, e.g. striped bass (*Morone saxatalis*), spotted sea trout (*Cynoscion nebulosus*), spot (*Leiostomus xanthurus*) and gag grouper (*Mycteroperca microlepis*)[5].

BIOGEOGRAPHY

The state of North Carolina is an interesting biogeographical boundary for seagrasses in the North Atlantic. On the east coast of the United States it is the southernmost limit for the distribution of the temperate seagrass *Zostera marina* and the northernmost limit for the distribution of the tropical seagrass *Halodule wrightii*[6]. Due to their existence at the limits of their thermal tolerance, the seagrasses found in this boundary zone are expected to show early effects of global warming in this area. *Ruppia maritima* is able to tolerate a broad range of temperatures and is found throughout the mid-Atlantic region and possibly along the coasts of South Carolina and Georgia.

Seagrasses in the mid-Atlantic region occur in wave-protected habitats. The extensive lagoon system (from Delaware to North Carolina) is delimited to the east by long barrier islands. These islands provide shelter from oceanic waves, making the lagoons ideal habitats for *Zostera marina, Ruppia maritima* and *Halodule wrightii*. No seagrasses (but seagrass wrack, including reproductive shoots with viable seeds) have been reported for the exposed shores of the Atlantic Ocean. The seagrasses in the mid-Atlantic region also colonize areas covering a wide range of salinities: from full-strength seawater (30-32 psu) near the mouths of the estuaries to mesohaline zones (10-20 psu) in the middle portion of the estuaries. Due to its ability to tolerate relatively low salinities, *Ruppia maritima* is usually the seagrass that extends farthest into the estuaries.

The distribution of seagrasses in the mid-Atlantic region is restricted to shallow waters because of the high suspended sediment and nutrient loadings leading to relatively turbid waters in seagrass habitats (light attenuation coefficients higher than 1 per m^2 are quite common). In relatively pristine areas (North Carolina sounds adjacent to barrier islands and Chincoteague Bay), the maximum depth to which seagrasses grow can be as great as 2 m, while in habitats associated with the mainland and eutrophic (i.e. nutrient enriched) conditions (Chesapeake Bay, North Carolina sounds near the mainland), the maximum vertical distribution only reaches depths of 0.5 to 1.0 m[7, 8]. In other areas, such as the Delaware coastal bays, seagrasses are almost completely absent due to high water turbidity.

HISTORICAL PERSPECTIVES

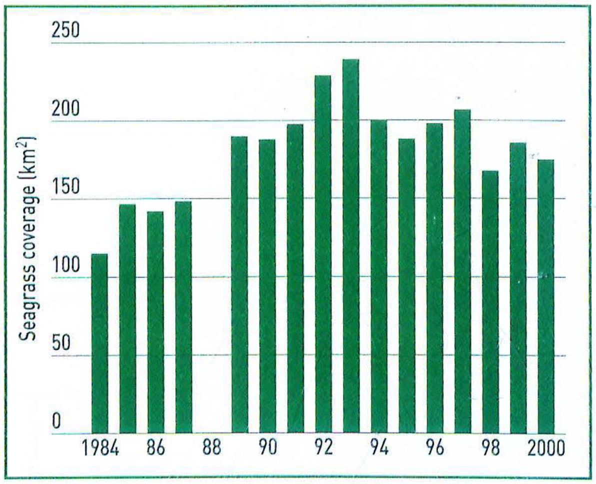
No record exists of the extent of the vegetation prior to the 1930s, but anecdotal evidence of historical changes in eelgrass[9, 10] suggest that seagrasses occurred in the Chesapeake Bay region in the mid- to late 1800s[11]. In the pre-colonial period (1800s), seagrasses are believed to have formed extensive beds in estuaries and lagoons in the mid-Atlantic region covering the coastal bays in their entirety. It is not known to what depths seagrasses used to grow in the estuaries, but it may have been as deep as 4 m. When *Zostera marina* beds were extensive, the seagrass was used for packing and upholstery stuffing. It was also used for insulation of buildings due to its low flammability and excellent insulating properties.

A massive decline of seagrasses in the mid-

Map 21.1
The mid-Atlantic coast of the United States

Atlantic region occurred in the 1930s as *Zostera marina* was affected, and in many locations eliminated, by wasting disease[12, 13]. The loss of eelgrass was reported throughout the northern Atlantic. In some areas in the mid-Atlantic (Chesapeake Bay, Chincoteague Bay, North Carolina sounds), eelgrass beds slowly recovered. In the Delaware coastal bays (Indian River and Rehoboth Bays), recovery of eelgrass through the 1950s ended, apparently due to eutrophication. In the coastal bays of the lower eastern shore of Virginia, eelgrass was completely eliminated and never

Figure 21.1
Seagrass distribution (mainly *Zostera marina* and *Ruppia maritima* but possibly also a few hectares of other SAV species) in Chesapeake Bay



Source: Based on data from the Virginia Institute of Marine Science SAV mapping program.

Figure 21.2
Changes in seagrass (*Zostera marina* and *Halodule wrightii*) distribution in the Cape Lookout area (southern Core Sound, North Carolina) between 1985 and 1988

Note: Areas of seagrass coverage that did not change between the two years are shown in green cross-hatch; areas of gain are shown by the vertical white hatching and areas of loss are shown by the horizontal white hatching.

Source: Poster produced by the Beaufort Lab entitled *SAV Habitat in 1985 and 1988: Cape Lookout to Drum Inlet, North Carolina*, by Randolph Ferguson, Lisa Wood and Brian Pawlak.

recovered. The decline in the 1930s was complicated by a hurricane of unprecedented proportions in August 1933. There is no evidence of eelgrass ever being present in Delaware Bay.

PRESENT DISTRIBUTION

Although rare, sparse and small eelgrass beds are present in the coastal bays of Delaware (a result of restoration efforts). They are too small to map and also ephemeral in nature. There is very little seagrass in the state of Delaware.

Unprecedented changes to eelgrass populations in Chesapeake Bay occurred following Tropical Storm Agnes in June 1972. Eelgrass beds in the upper portions of Chesapeake Bay were the most influenced by the effects of the runoff (low salinities and high turbidity), which occurred during the peak growth period for eelgrass. While the distribution of seagrasses in Chesapeake Bay (Maryland and Virginia) had been partially documented in 1971 and 1974, the first baywide survey was conducted in 1978, and annual surveys began in 1984. Based on these data, seagrass distribution in Chesapeake Bay was observed to increase 63 percent between 1985 and 1993, but distribution then declined 27 percent between 1993 and 2000 (Figure 21.1). In contrast, from 1986 to 2000, seagrass distribution in the coastal bays of Maryland and Virginia increased 238 percent (see Case Study 21.1). Presently, the seagrasses in Chesapeake Bay show declines in some areas while recovering in others. There is great interannual variation, making it difficult to estimate the area of seagrass.

In North Carolina, where the seagrass habitats are dominated by shallow areas protected by extensive barrier islands, seagrass distribution has only recently been mapped. Core Sound was mapped in 1988 and inside of Cape Hatteras in 1990. The area south of Cape Lookout has not yet been mapped but it is known that no seagrasses are found south of Sneads Ferry (80 km north of the city of Wilmington)[14]. The lack of seagrasses in Albermarle Sound is believed to be the result of the high water turbidity in this area. The western portion of Pamlico Sound is also mostly unvegetated due to the long fetch and consequent high turbidity during strong wind events. Although there has not been a sustained effort to map seagrasses in North Carolina, researchers have been investigating aspects of seagrass ecology and report no noticeable changes in species composition or distribution since the 1970s[15]. One quantitative effort (Figure 21.2) confirms this. In the Core Sound area (between Drum Inlet and Cape Lookout) seagrass distribution was generally consistent between the two years in which it was mapped. In 1985 there were 7 km^2 of seagrass and in 1988 there were 6.6 km^2, only a 5.7 percent loss. There were 151 beds in 1985 and 149 in 1988. Two anthropogenic impacts on seagrasses were noted between 1985 and 1988: a clam harvesting operation dug up seagrasses, while in another area dredge spoil was deposited on a seagrass bed[16]. In North Carolina, seagrass beds have been relatively stable since the 1970s at approximately 80 km^2. It is not clear if seagrass beds in North Carolina also suffered the declines observed in the Chesapeake Bay before researchers began to work in these habitats in the 1970s. *Zostera marina* was affected by the wasting disease of the 1930s in North Carolina, but recovered, as in Chincoteague Bay.

PRESENT THREATS

The main threats to seagrasses in the mid-Atlantic region today are eutrophication and high turbidity from poor land-management practices. As the coastal zone continues to be developed, nutrient loads and suspended sediments in the water column tend to increase[17]. These nutrients may come from well-defined sources such as a sewage treatment plant, a pig farm or a golf course, but a large amount of nutrients also comes from non-point sources such as farmland and groundwater nutrient enrichment by septic systems. As a result of increased nutrient loading, epiphytic algae may grow directly on the seagrass leaves while blooms of phytoplankton or macroalgae may occur in the water column. These processes decrease the amount of light that reaches the seagrasses and cause their decline or death. Most water bodies in the mid-Atlantic are now phytoplankton dominated, and the few pristine lagoons are showing signs of deterioration resulting from blooms of nuisance macroalgae such as *Chaetomorpha linum* and *Ulva lactuca* (mats up to 1.5 m thick). These algal blooms have adversely impacted healthy seagrass beds (see Case Study 21.1) as well as recent eelgrass restoration efforts in the Delaware coastal bays.

Seagrass beds are vulnerable to disruption by commercial fishing practices, especially clam and scallop dredging. Hydraulic clam dredging digs deep trenches or circles into the sediments (see Case Study 21.1). If these are vegetated by seagrasses, the plants are lost and the recovery is relatively slow[18]. Clam dredging also has a negative impact on other fisheries. The trenches caused by hydraulic clamming in seagrass beds prevent crabbers from pulling their scrapes through the seagrass beds (a practice that causes relatively little damage to the plants), directly threatening their livelihood.

As coastal areas become more heavily populated, more individuals also want to enjoy water-related activities. Boat-generated waves and turbulence have a negative impact on seagrasses and their habitats[19]. There is also no doubt that propeller scars have a detrimental effect on seagrasses[20,21]. The effect is similar to that described for clam dredging although the scars are narrower. This problem is most severe in North Carolina but has also been documented in Maryland and Virginia.

Dredging and maintenance dredging of channels is a threat to seagrasses in all mid-Atlantic states. This operation increases the turbidity of the water, may bury seagrasses and may increase the nutrient concentration in the water column. Regulations in North Carolina suggest (but do not require) that damage to seagrasses be minimized during dredging activities. Maryland is currently re-evaluating its dredging regulations.

Sea-level rise has the potential to pose a threat to seagrasses in the mid-Atlantic. The vulnerability of coastal zones to sea-level rise has been classified as very high in this region, the highest risk on the east coast of the United States. Unfortunately, our understanding of how sea-level rise affects seagrasses is in its infancy. It is known that sea-level rise leads to marsh erosion[22-24] and the eroded sediments are then transported to coastal waters where seagrass beds may occur. This may lower the light available to seagrasses and may lead to their decline or loss. The loss of the seagrasses could then lead to further coastal erosion due to the loss of wave attenuation previously provided by the seagrasses.

Although a natural event, a storm can be detrimental to seagrasses. Hurricanes are quite common in the mid-Atlantic, especially in the state of North Carolina, and have shown to be detrimental to seagrasses by removing the plants, eroding the sediment, burying seagrass beds and/or increasing turbidity of the water[25]. It is expected that with global warming hurricane frequency and intensity will increase. With that, the threat to seagrasses is also expected to increase. However, little quantitative data exist on the effects of hurricanes on long-term stability of seagrass beds in this region. Hurricanes are more frequent in the fall period (September and October) and it is possible that water quality effects may be marginal as temperatures are lower and growth is generally less than in the spring.

POLICIES AND REGULATIONS

No state or federal marine parks exist in the mid-Atlantic region, but several protected islands include the adjacent waters in their jurisdiction. The national estuarine research reserves in Maryland and North Carolina include seagrass habitats, although no protection is afforded by this designation. The Assateague Island National Seashore Park protects its adjacent seagrasses. The state of Delaware currently has no protection for seagrasses in its regulatory framework. The total area of protected seagrass beds has not been identified for the mid-Atlantic.

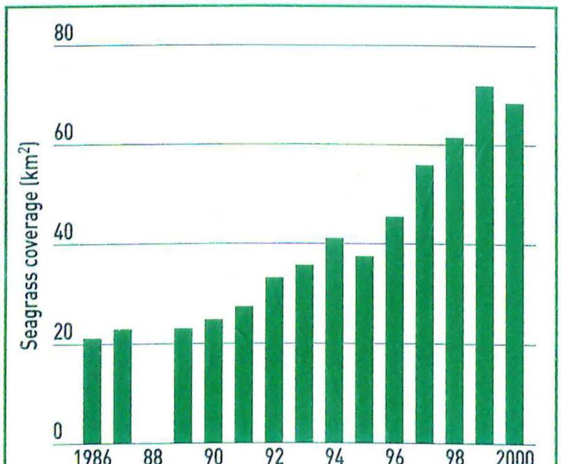
At the federal level, seagrasses are afforded some protection under Section 404 of the Clean Water Act (33 USC 1341-1987) and Section 10 of the Rivers and Harbors Act (33 USC 403), which regulate the discharge of dredged or fill material into US waters. Authority for administering the Clean Water Act rests with the US Environmental Protection Agency. Seagrass protection under the Act is provided by a federal permit program that is delegated to and administered by the US Army Corps of Engineers. Potential impacts on "special aquatic sites", such as seagrass beds, are considered in the permit review process. Section 10 of the Rivers and Harbors Act, also administered by the Army Corps, regulates all activities in navigable waters including dredging and placement of structures.

On a regional basis, considerable and cooperative efforts by scientists, politicians, federal and state resource managers, and the general public have developed policies and plans to protect, preserve and enhance the seagrass populations of Chesapeake Bay[26]. The foundation for the success of these management efforts has been the recognition of the habitat value of seagrasses to many fish and shellfish, and the elucidation of linkages between seagrass habitat health and water quality conditions. Because of these linkages, the distribution of seagrasses in Chesapeake Bay and its tidal tributaries is being used

Case Study 21.1

SEAGRASSES IN CHINCOTEAGUE BAY: A DELICATE BALANCE BETWEEN DISEASE, NUTRIENT LOADING AND FISHING GEAR IMPACTS

Chincoteague Bay is one of the most pristine water bodies in the mid-Atlantic. It is a relatively shallow coastal lagoon (average depth 1.2 m) with limited freshwater input and long residence times (flushing of 7.5 percent per day). Salinities are close to those of seawater (26-31 psu) and nutrient levels are relatively low (<10 μM total nitrogen, <4 μM phosphate[29]). The western shore of Chincoteague Bay is characterized by extensive salt marshes and isolated, small towns representing an area of low developmental pressure (less than 0.04 person per hectare). The eastern shore is located adjacent to an unpopulated (but accessible to tourists) barrier island (Assateague Island National Seashore) with an extensive dune system along the Atlantic coast and marshes along the Chincoteague Bay shoreline.



Recovery and recent decline of seagrass (*Zostera marina* and *Ruppia maritima*) distribution in Chincoteague Bay.

Seagrasses in Chincoteague Bay are found almost exclusively on the eastern shores. Due to its relatively shallow depth, it is believed that the entire bay used to be colonized by *Zostera marina*. In the 1930s, *Zostera marina* disappeared as a result of wasting disease after which it slowly began to recolonize the eastern shore. The recovery of the seagrasses in Chincoteague Bay has been well documented since 1986 (see figure, left). Although there was a 40 percent increase in the human population on the western shore of Chincoteague Bay between 1980 and 2000, the total nitrogen and phosphorus loadings declined between 1987 and 1998 (in some areas as much as 50 percent). This is believed to be due to the construction of sewage treatment plants and the reduction of the amount of fertilizers used on the farms west of Chincoteague Bay. As a result, phytoplankton concentration is low and light penetration relatively deep. Seagrasses flourished during this period showing a 238 percent increase in distribution between 1986 and 1999. In 1996, seagrasses even began colonizing the western shore which had remained unvegetated since the 1930s.

One of the first threats to seagrass in Chincoteague Bay since its decimation in the 1930s came from a fisheries practice[28]. In 1997, severe damage to the seagrass beds was noted and attributed to two types of hard clam fishing gear: hydraulic dredges and modified oyster dredges (see as an initial measure of progress in the restoration of living resources and water quality. Restoration targets and goals have been established to link demonstrable improvements in water quality to increases in seagrass abundance[27]. The states of Maryland and Virginia each have separate regulatory agencies to oversee activities that could be injurious to seagrass populations. Both states are committed to protecting seagrass habitat while maintaining viable commercial fisheries and aquaculture operations.

Maryland State Code COMAR 4-213 specifically prohibits damage to seagrasses for any reason except for commercial fishing activities and certain specific situations such as clearing seagrasses from docks, piers and navigable waters. If seagrasses will be adversely affected, the Maryland Department of the Environment and the Maryland Department of Natural Resources are responsible for issuing a permit, which includes a plan showing the site at which the activity is proposed, a dated map of current seagrass distribution and the extent of seagrass to be removed. Maryland does prohibit one type of commercial fishing activity, hydraulic clam dredging, in specific regions of its state waters. Hydraulic clam dredging is prohibited both within a specified distance from shore, which varies by political boundaries (NRA 4-1038), and in existing seagrass beds (NR 4-1006.1), as determined by annual aerial mapping surveys.

In Virginia, permits to use state-owned submerged lands now include seagrass presence as a factor to be considered in the application process (Code 28.2-1205 (A) [6], amended in 1996). On-bottom shellfish

photograph, right). The seagrass area affected by hydraulic dredging increased from 0.53 km^2 in 1996 to 5.08 km^2 in 1997, while modified oyster dredge scars increased from 10 in 1995 to 218 scars in 1997. Analysis of the recovery from both types of scarring showed that some scars require more than three years to revegetate to undisturbed levels. Once notified of these impacts, resource managers in Maryland and Virginia responded within several months to protect seagrasses through law and regulation preventing clam dredging within seagrass beds. In Virginia, the new regulation was successful in reducing scarring, but required later revisions for successful enforcement. In Maryland, however, procedural requirements to fully implement the law required additional time, during which scarring increased to 12.57 km^2 in 1999. This issue has demonstrated the importance of close linkages between the scientific research community, politicians, management agencies, law enforcement agencies and the public, as well as the importance of sanctuaries or protection zones to prevent damage to critical seagrass habitats.

Over the last three years, seagrasses in Chincoteague Bay have been exposed to another stress: the blooms of the nuisance macroalga *Chaetomorpha linum*, suggesting that this formerly pristine area may be experiencing eutrophication. Indeed, nutrient data shows a renewed increase in total nitrogen and phosphorus loads in 1999 and 2000. While pristine systems are dominated by seagrasses, systems in the early and late stages of eutrophication are dominated by macroalgae and/or phytoplankton, respectively[30]. The macroalgal mats observed in Chincoteague Bay over the last two years can be as thick as 1.5 m, killing the seagrasses beneath and leaving long scars visible via aerial photography. Managers are currently attempting to determine the source of the nutrients fueling these macroalgal blooms and threatening the seagrasses of Chincoteague Bay.

Photo: B. Orth

Aerial photograph taken in 1998 of a portion of Chincoteague Bay, Virginia, seagrass bed showing damage to the bed from a modified oyster dredge.

Notes: Arrows point to circular "donut-shaped" scars created by the dredge being pulled by a boat in a circular manner. The light areas in each circle represent areas that had vegetation that was uprooted and are now unvegetated. The dark spot within each circle is seagrass that was not removed. The long, light-colored streaks emanating from some of the scars are sediment plumes created by the digging activities of sting rays.

aquaculture activities requiring structures are now prohibited from being placed on existing seagrass beds (4-VAC 20 335-10, effective January 1998). In 1999, the Virginia Marine Resources Commission was directed (Code 28.2-1204.1) to develop guidelines with criteria to define existing beds and to delineate potential restoration areas. Dredging for clams (hard and soft) in Virginia is prohibited in waters less than 1.2 m where seagrasses are likely to occur. A special regulation was passed for seagrasses in the Virginia portion of Chincoteague Bay (4-VAC 20-1010) where clam and crab dredging is prohibited within 200 m of seagrass beds. Because of enforcement issues, the Virginia regulation has recently been modified (4-VAC 20-70-10 seq.) to include permanent markers with signs delineating the protected seagrass[28].

In the state of North Carolina, regulations involving seagrasses are not as strong as in Virginia and Maryland. North Carolina protects seagrass beds along underdeveloped areas. These areas are to be used mainly for education and research although some recreational activities are permitted. The dredging of channels is regulated such that seagrass beds must be avoided. Damage to seagrasses is also to be minimized when docks, piers, bulkheads, boat ramps, groins, breakwaters, culverts and bridges are constructed.

ACKNOWLEDGMENTS

Mark Finkbeiner, Ben Anderson and Brian Glazer are thanked for their help and for sharing their data. Mike Durako and Mark Fonseca contributed valuable information. Lisa Wood and Randolph Ferguson developed the seagrass vectors in Figure 21.2. Mike Naylor and several of the above listed colleagues provided comments on the report. Melissa Wood and Dave Wilcox provided technical support. This is contribution number 3613 from Horn Point Laboratory, University of Maryland Center for Environmental Science and contribution number 2491 from the Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia.

AUTHORS

Evamaria W. Koch, Horn Point Laboratory, University of Maryland Center for Environmental Science, P.O. Box 775, Cambridge, MD 21613, USA. **Tel:** +1 410 221 8418. **Fax:** +1 410 221 8490. **E-mail:** koch@hpl.umces.edu

Robert J. Orth, Virginia Institute of Marine Science, School of Marine Science, College of William and Mary, Gloucester Point, VA 23062, USA.

REFERENCES

1 Orth R, Heck JKL Jr, Diaz RJ [1991]. Littoral and intertidal systems in the mid-Atlantic coast of the United States. In: Mathieson AC, Nienhuis PH (eds) *Ecosystems of the World 24: Intertidal and Littoral Ecosystems of the World*. Elsevier, Amsterdam. pp 193-214.
2 Orth R [1976]. The demise and recovery of eelgrass, *Zostera marina*, in the Chesapeake Bay, Virginia. *Aquatic Botany* 2: 141-159.
3 Moore KA, Wilcox DJ, Orth RJ [2000]. Analysis of the abundance of submersed aquatic vegetation communities in the Chesapeake Bay. *Estuaries* 23: 115-127.
4 Fredette TJ, Diaz RJ, van Montfrans J, Orth RJ [1990]. Secondary production within a seagrass bed (*Zostera marina* and *Ruppia maritima*) in lower Chesapeake Bay. *Estuaries* 13: 431-440.
5 Ross SW, Moser ML [1995]. Life history of juvenile gag, *Mycteroperca microlepis*, in North Carolina estuaries. *Bulletin of Marine Science* 56: 222-237.
6 Ferguson RL, Pawlak BT, Wood LL [1993]. Flowering of the seagrass *Halodule wrightii* in North Carolina, USA. *Aquatic Botany* 46: 91-98.
7 Dennison WC, Orth RJ, Moore KA, Stevenson JC, Carter V, Kollar S, Bergstrom P, Batiuk RA [1993]. Assessing water quality with submersed aquatic vegetation. *Bioscience* 43: 86-94.
8 Ferguson RL, Korfmacher K [1997]. Remote sensing and GIS analysis of seagrass meadows in North Carolina, USA. *Aquatic Botany* 58: 241-258.
9 Cottam C [1934]. Past periods of eelgrass scarcity. *Rhodora* 36: 261-264.
10 Cottam C [1935]. Further notes on past periods of eelgrass scarcity. *Rhodora* 37: 269-271.
11 Orth RJ, Moore KA [1984]. Distribution and abundance of submersed aquatic vegetation in Chesapeake Bay: An historical perspective. *Estuaries* 7: 531-540.
12 Renn CE [1934]. Wasting disease of *Zostera* in American waters. *Nature* 134: 416.
13 Tutin TG [1938]. The autecology of *Zostera marina* in relation to its wasting disease. *New Phytology* 37: 50-71.
14 Durako. Personal communication.
15 Fonseca MS. Personal communication.
16 Finkbeiner. Personal communication.
17 Kemp WM, Twilley RT, Stevenson JC, Boynton WR, Means JC [1983]. The decline of submerged vascular plants in Upper Chesapeake Bay: Summary of results concerning possible causes. *Marine Technology Society Journal* 17: 78-89.
18 Stephan CD, Peuser RL, Fonseca MS [2000]. *Evaluating Fishing Gear Impacts to Submerged Aquatic Vegetation and Determining Mitigation Strategies*. Atlantic States Marine Fisheries Commission Habitat Management Series 5. 35 pp.
19 Koch EW [2002]. The impact of boat-generated waves on a seagrass habitat. *Journal of Coastal Research* 37: 66-74.
20 Clark PA [1995]. Evaluation and management of propeller damage to seagrass beds in Tampa Bay, Florida. *Florida Scientist* 58: 193-196.
21 Dawes CJ, Andorfer J, Rose C, Uranowski C, Ehringer N [1997]. Regrowth of the seagrass *Thalassia testudinum* into propeller scars. *Aquatic Botany* 59: 139-155.
22 Kearney MS, Stevenson JC, Ward LG [1994]. Spatial and temporal changes in marsh vertical accretion rates at Monie Bay: Implications for sea-level rise. *Journal of Coastal Research* 10: 1010-1020.
23 Ward LG, Kearney MS, Stevenson JC [1998]. Variations in sedimentary environments and accretionary patterns in estuarine marshes undergoing rapid submergence, Chesapeake Bay. *Marine Geology* 151: 111-134.
24 Rooth JE, Stevenson JC [2000]. Sediment deposition patterns in *Phragmites australis* communities: Implications for coastal areas threatened by rising sea-level. *Wetlands Ecology and Management* 8: 173-183.

25 Fonseca MS, Kenworthy WJ, Whitfield PE [2000]. Temporal dynamics of seagrass landscapes: A preliminary comparison of chronic and extreme disturbance events. In: Pergent G, Pergent-Martini C, Buia MC, Gambi MC (eds) *Proceedings 4th International Seagrass Biology Workshop, Sept. 25-Oct. 2, 2000, Corsica, France.* pp 373-376.

26 Orth RJ, Batiuk RA, Bergstrom PW, Moore KA [2002a, in press]. A perspective on two decades of policies and regulations influencing the protection and restoration of submerged aquatic vegetation in Chesapeake Bay, USA. *Bulletin of Marine Science.*

27 Batiuk RA, Orth RJ, Moore KA, Dennison WC, Stevenson JC, Staver LW, Carter V, Rybicki NB, Hickman RE, Kollar S, Bieber S, Heasly P [1992]. Chesapeake Bay Submerged Aquatic Vegetation Habitat Requirements and Restoration Targets: A Technical Synthesis. Chesapeake Bay Program, Annapolis, MD, CBP/TRS 83/92. 248 pp.

28 Orth RJ, Fishman JR, Wilcox DW, Moore KA [2002]. Identification and management of fishing gear impacts in a recovering seagrass system in the coastal bays of the Delmarva Peninsula, USA. *Journal of Coastal Research* 37: 111-119.

29 Boynton WR, Murray L, Hagy JD, Stokes C, Kemp WM [1996]. A comparative analysis of eutrophication patterns in a temperate coastal lagoon. *Estuaries* 19: 408-421.

30 Valiela I, McClelland J, Hauxwell J, Behr PJ, Hersh D, Foreman K [1997]. Macroalgal blooms in shallow estuaries: Controls and ecophysiological and ecosystem consequences. *Limnology and Oceanography* 42: 1105-1118.