A Global Crisis for Seagrass Ecosystems

ROBERT J. ORTH, TIM J. B. CARRUTHERS, WILLIAM C. DENNISON, CARLOS M. DUARTE, JAMES W. FOURQUREAN, KENNETH L. HECK JR., A. RANDALL HUGHES, GARY A. KENDRICK, W. JUDSON KENWORTHY, SUZANNE OLYARNIK, FREDERICK T. SHORT, MICHELLE WAYCOTT, AND SUSAN L. WILLIAMS

Seagrasses, marine flowering plants, have a long evolutionary history but are now challenged with rapid environmental changes as a result of coastal human population pressures. Seagrasses provide key ecological services, including organic carbon production and export, nutrient cycling, sediment stabilization, enhanced biodiversity, and trophic transfers to adjacent habitats in tropical and temperate regions. They also serve as "coastal canaries," global biological sentinels of increasing anthropogenic influences in coastal ecosystems, with large-scale losses reported worldwide. Multiple stressors, including sediment and nutrient runoff, physical disturbance, invasive species, disease, commercial fishing practices, aquaculture, overgrazing, algal blooms, and global warming, cause seagrass declines at scales of square meters to hundreds of square kilometers. Reported seagrass losses have led to increased awareness of the need for seagrass protection, monitoring, management, and restoration. However, seagrass science, which has rapidly grown, is disconnected from public awareness of seagrasses, which has lagged behind awareness of other coastal ecosystems. There is a critical need for a targeted global conservation effort that includes a reduction of watershed nutrient and sediment inputs to seagrass habitats and a targeted educational program informing regulators and the public of the value of seagrass meadows.

Keywords: seagrass, decline, sentinels, ecological services, monitoring

Seagrasses—a unique group of flowering plants that have adapted to exist fully submersed in the sea—profoundly influence the physical, chemical, and biological environments in coastal waters, acting as ecological engineers (*sensu* Wright and Jones 2006) and providing numerous important ecological services to the marine environment (Costanza et al. 1997). Seagrasses alter water flow, nutrient cycling, and food web structure (Hemminga and Duarte 2000). They are an important food source for megaherbivores such as green sea turtles, dugongs, and manatees, and provide critical habitat for many animals, including commercially and recreationally important fishery species (figure 1; Beck et al. 2001). They also stabilize sediments and produce large quantities of organic carbon. However, seagrasses and these associated ecosystem services are under direct threat from a host of anthropogenic influences.

Seagrasses are distributed across the globe (figure 2), but unlike other taxonomic groups with worldwide distribution, they exhibit low taxonomic diversity (approximately 60 species worldwide, compared with approximately 250,000 terrestrial angiosperms). The three independent lineages of seagrass (Hydrocharitaceae, Cymodoceaceae complex, and Zosteraceae) evolved from a single lineage of monocotyledonous flowering plants between 70 million and 100 million years ago (figure 3a; Les et al. 1997). This is in stark contrast to other plant groups that have colonized the marine envi-

Robert J. Orth (e-mail: jjorth@vims.edu) is a professor in the School of Marine Science, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA 23062. Tim J. B. Carruthers is a science integrator and William C. Dennison is vice president for science applications and a professor at the Integration and Application Network, University of Maryland Center for Environmental Science, Cambridge, MD 21613. Carlos M. Duarte is a research professor at the Instituto Mediterráneo de Estudios Avanzados, Consejo Superior de Investigaciones Científicas/Universidad de las Islas Baleares, Calle Miquel Marqués 21, 07190 Esporles, Islas Baleares, Spain. James W. Fourqurean is department chair of biological sciences and a member of the Southeast Environmental Research Center, Florida International University, Miami, FL 33199. Kenneth L. Heck Jr. is a professor and chair of university programs at the Dauphin Island Sea Lab, Dauphin Island, AL 36528. A. Randall Hughes is a postdoctoral researcher, Suzanne Olyarnik is a graduate student, and Susan L. Williams is a professor at the University of California at Davis; Hughes, Olyarnik, and Williams are also associated with the Bodega Marine Laboratory, Bodega Bay, CA 94923. Gary A. Kendrick is an associate professor at the School of Plant Biology, University of Western Australia, Crawley 6009, Western Australia. W. Judson Kenworthy is a research biologist at the Center for Coastal Fisheries and Habitat Research, National Ocean Service, National Oceanic and Atmospheric Administration, Beaufort, NC 28516. Frederick T. Short is a research professor in the Department of Natural Resources and chair of the Natural Resources and Earth Systems Science PhD program at the University of New Hampshire, Jackson Estuarine Laboratory, Durham, NH 03824. Michelle Waycott is a senior lecturer in the School of Marine and Tropical Biology, James Cook University, Townsville, 4811 Queensland, Australia.

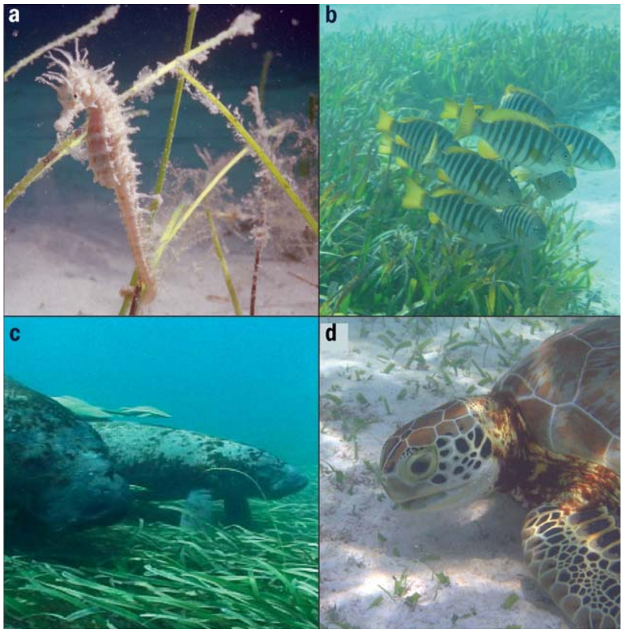

*Figure 1. Examples of seagrass meadows and associated animals. (a) Seahorse (***Hippocampus** *sp.) in temperate* **Cymodocea nodosa** *meadow, Mediterranean Sea. Photograph: Gérard Pergent. (b) School of zebrafish (***Girella zebra***) over a temperate* **Posidonia australis** *meadow, Western Australia. Photograph: Gary A. Kendrick. (c) Manatee (***Trichechus manatus***) feeding in a tropical* **Thalassia testudinum** *meadow, Puerto Rico. Photograph: James Reid. (d) Green sea turtle (***Chelonia midas***) feeding in a tropical* **T. testudinum** *meadow, Yucatán. Photograph: Robert P. van Dam.*

ronment, such as salt marsh plants, mangroves, and marine algae, which are descended from multiple and diverse evolutionary lineages. In spite of their low species diversity and unique physiological characteristics, seagrasses have successfully colonized all but the most polar seas (figure 2). Compared with seagrass meadows, the other major coastal marine habitats are geographically restricted to much smaller latitudinal ranges (mangroves and coral reefs in tropical regions, kelp beds and salt marshes in temperate regions).

Seagrasses have developed unique ecological, physiological, and morphological adaptations to a completely submersed existence, including internal gas transport, epidermal chloroplasts, submarine pollination, and marine dispersal (den Hartog 1970, Les et al. 1997). To provide oxygen to their roots and rhizomes, often growing in highly reducing sediments with toxic sulfide levels, and to support large amounts of nonphotosynthetic tissue (Terrados et al. 1999), seagrasses require some of the highest light levels of any plant group worldwide (approaching 25% of incident radiation in some seagrass species, compared with 1% or less for other angiosperm species; Dennison et al. 1993). These extremely high light requirements mean that seagrasses are acutely responsive to environmental changes, especially those that alter water clarity. Although it is true that the global distribution and abundance of seagrasses have changed over evolutionary time in response to sea-level change, physical modification of coastlines (figure 3a, 3b), and global changes in atmospheric carbon dioxide (CO_2) concentration and water temperature (figure 3c; Crowley 1990, Berner and Kothavala 2001), the very gradual changes in environmental conditions over the history of seagrass evolution are overshadowed by current changes to the coastal zone resulting from increased human pressures. These pressures result in the degradation of estuaries and coastal seas, producing changes to species and habitats (Lotze et al. 2006). These rapid contemporary changes have been caused by a multitude of mechanisms, including increased nutrient and sediment runoff, invasive species, hydrological alterations, and commercial fishing practices. As a result, reported seagrass losses worldwide have been accumulating.

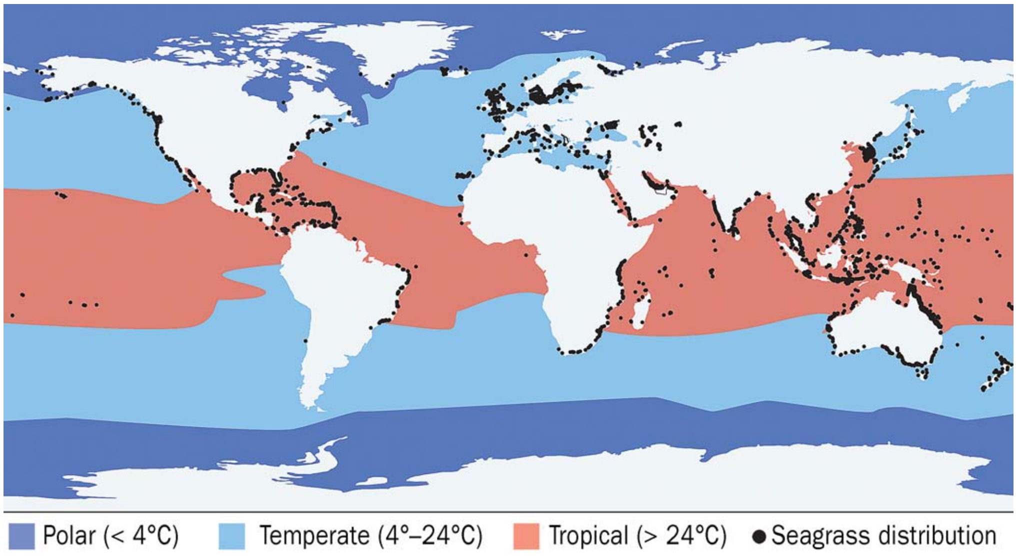

Figure 2. Current global distribution of seagrass in relation to mean ocean temperature. Regional divisions are based on polar (< 4 degrees Celsius [°C]), temperate (4°C–24°C), and tropical (> 24°C) climate (Green and Short 2003).

Seagrasses as ecological service providers and biological sentinels

Seagrass meadows have important ecological roles in coastal ecosystems and provide high-value ecosystem services compared with other marine and terrestrial habitats (figure 4; Costanza et al. 1997). For example, primary production from seagrasses and their associated macro- and microepiphytes rivals or exceeds that of many cultivated terrestrial ecosystems (Duarte and Chiscano 1999). Seagrasses also provide an enormous source of carbon to the detrital pool, some of which is exported to the deep sea, where it provides a critical supply of organic matter in an extremely food-limited environment (Suchanek et al. 1985). Much of the excess organic carbon produced is buried within seagrass sediments, which are hotspots for carbon sequestration in the biosphere (Duarte et al. 2005). The structural components of seagrass leaves, rhizomes, and roots modify currents and waves, trapping and storing both sediments and nutrients, and effectively filter nutrient inputs to the coastal ocean (Hemminga and Duarte 2000). Biodiversity in seagrass meadows is greater than in adjacent unvegetated areas, and faunal densities are orders of magnitude higher inside the meadows (Hemminga and Duarte 2000). They also serve as a nursery ground, often to juvenile stages of economically important species of finfish and shellfish, although the species vary by region and climate (figure 4; Beck et al. 2001, Heck et al. 2003). The large-scale loss of seagrass that occurred on both sides of the North Atlantic Ocean in the early 1930s, a result of "eelgrass wasting disease" (Rasmussen 1977), had many effects on the ecosystem. Associated with this loss were a collapse of scallop fisheries and dramatic reductions in waterfowl populations. In addition, it resulted in the only known case of an extinction of a marine gastropod (Carlton et al. 1991). Finally, the proximity of seagrass beds to other critical habitats, such as salt marshes (in temperate regions) or mangroves and coral reefs (in tropical regions), facilitates trophic transfers and cross-habitat utilization by fishes and invertebrates (Beck et al. 2001). This provides an energy subsidy that may be essential in maintaining the abundance of some coral reef fish species (Valentine and Heck 2005).

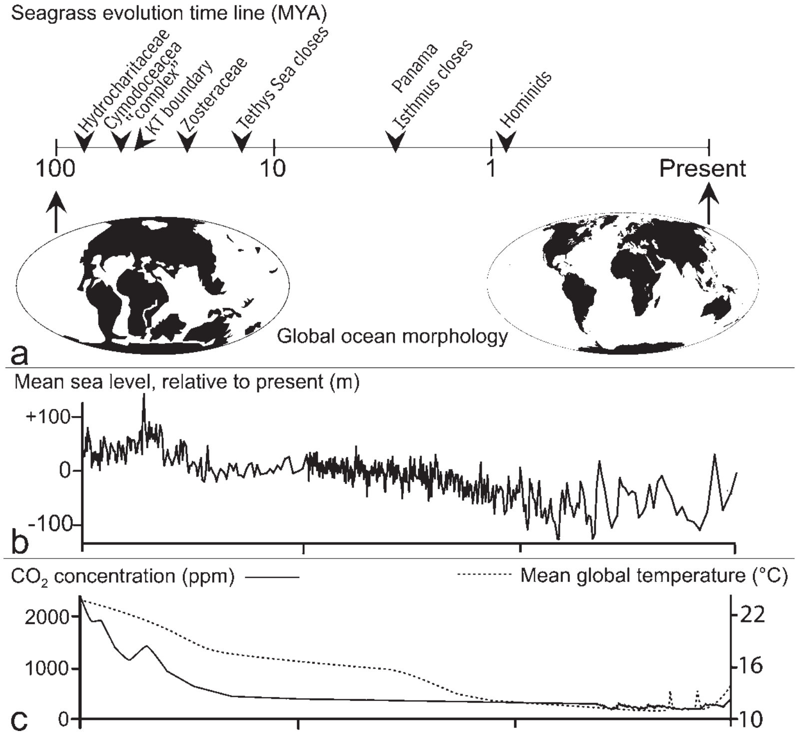

Figure 3. Seagrass evolution time line for the past 100 million years during periods of changing (a) global ocean structure (Dietz and Holden 1970), (b) mean sea level (Miller et al. 2005), and (c) atmospheric carbon dioxide (CO_2) concentration (Berner and Kothavala 2001) and mean global temperature (Crowley 1990). Abbreviations: °C, degrees Celsius; KT, Cretaceous–Tertiary (approximately 65 million years ago [MYA]); m, meters; ppm, parts per million.

Moreover, seagrasses can be considered as biological sentinels, or "coastal canaries." Changes in seagrass distribution, such as a reduction in the maximum depth limit (Abal and Dennison 1996) or widespread seagrass loss (Cambridge and McComb 1984), signal important losses of ecosystem services that seagrasses provide. Seagrasses are sessile, essentially integrating the relevant water quality attributes, such as chlorophyll and turbidity, that affect the light reaching their leaves. Several features of seagrasses and seagrass meadows result in their particular importance in this regard. The widespread distribution of seagrasses throughout tropical and temperate regions (figure 2) allows better assessment of larger-scale trends than do other comparable coastal habitats, such as mangrove, corals, or salt marsh plants, which are limited to only one of these broad geographic regions. Seagrasses also live in shallow, protected coastal waters, directly in the path of watershed nutrient and sediment inputs, and are therefore highly susceptible to these inputs (figure 4), unlike mangrove forests (which are largely unaffected by water quality) or coral reefs (which occur farther away from the imputs).

Another feature that makes seagrasses a valuable biological indicator is that they integrate environmental impacts over measurable and definable timescales (Longstaff and Dennison 1999, Carruthers et al. 2002), and a number of key examples support this concept. Increased coastal development leading to nutrient inputs in Cockburn Sound, Australia, led to large-scale losses of seagrass into the 1990s, and seagrasses remain at low levels in the area today (Walker et al. 2006). The loss of seagrass led to sediment resuspension, hampering restoration efforts and negatively affecting fish populations. In this region of Australia, if seagrass density drops below the 25th percentile of the long-term average for two consecutive years, remedial action is now mandated by law in confronting diffuse sources of pollution. Because of the susceptibility of seagrasses to such stresses and the high level of ecosystem services they provide, seagrasses are also used as one of the five sensitive indicators of pollution in the US National Estuarine Eutrophication Assessment (Bricker et al. 2003). And in the Chesapeake Bay, historical levels of

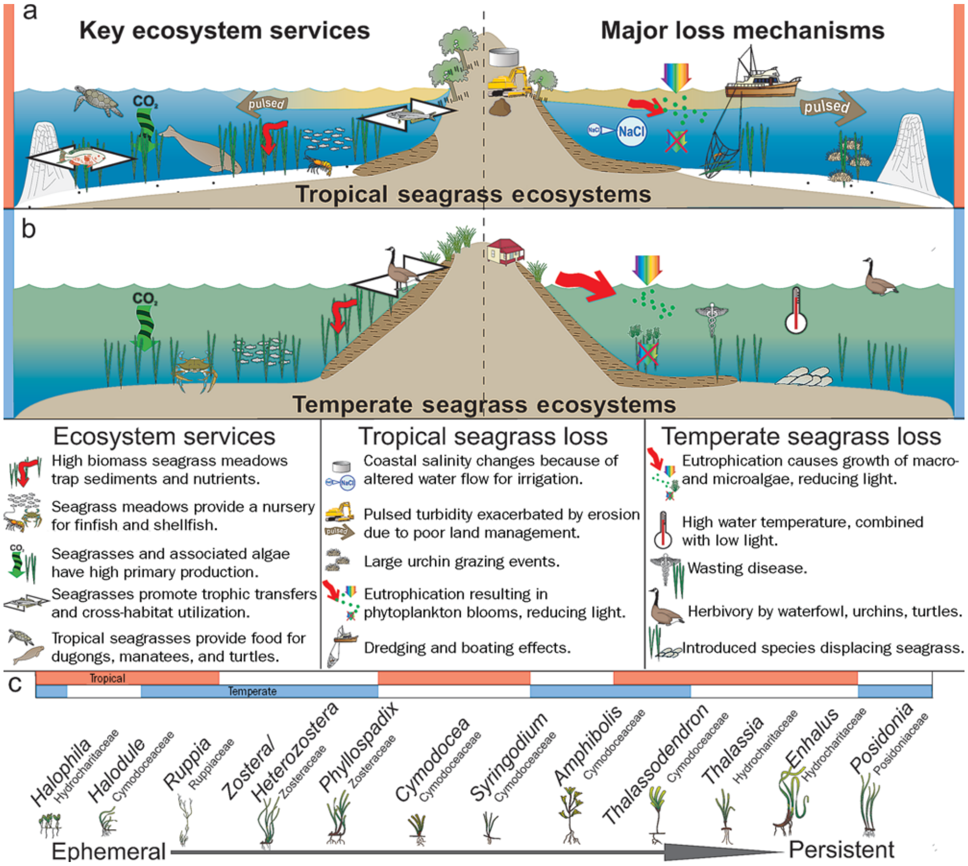

Figure 4. Conceptual diagrams for (a) tropical and (b) temperate seagrass ecosystems, detailing key ecosystem services and major mechanisms of seagrass loss. (c) Temperate and tropical seagrass genera (and family names), from ephemeral to persistent.

seagrass abundance (based on an assessment of historical photography) are being used as a target for the attainment of improved water quality from comprehensive nutrient and sediment management strategies (Orth et al. 2002).

The challenge of rapid environmental changes

Seagrasses now live in a marine environment with a lower mean temperature and lower availability of CO_2 than were experienced by their ancestors (Beer and Koch 1996). The recent trends of increasing global temperature, sea-level rise, and CO_2 concentrations (figure 3c, 5a, 5b) could result in environments that are potentially more conducive for many seagrass species. However, as a result of increased human population (figure 5c) and concomitant increased anthropogenic pressure to the coastal zone, the rates of change in coastal waters today are much faster than those experienced in the previous 100 million years of evolutionary history, and may well be too fast to allow these species to adapt. Where human activities have led to a reduction in the genetic diversity of seagrasses, these species' adaptation could be compromised (Williams 2001). In many areas, human alterations to the coastal zone (coastal hardening through breakwaters, harbors, and groins) have led to a situation that prevents the shoreward migration of the seagrasses necessitated by sea-level rise. In addition, significant seagrass habitat continues to be lost to coastal development (marinas, canal estates, and industry), leading to meadow fragmentation, with unknown consequences for long-term survival (Fonseca et al. 2000).

Seagrass meadows are increasingly being recognized for their dynamic nature, in many cases on an interannual basis, with a dynamic equilibrium at broad spatial scales (square kilometers) even in areas where water quality remains high (Fonseca et al. 2000, Kendrick et al. 2000). But this awareness is being overshadowed by rapid, large-scale seagrass losses over relatively short temporal scales throughout the world, in places such as the European Mediterranean (Marbà et al. 2005), Japan (Environment Agency of Japan 2000), the Chesapeake Bay (Orth and Moore 1983) and Florida Bay (Fourqurean and Robblee 1999) in North America, and Cockburn Sound (Walker et al. 2006) and Western Port (Bulthuis 1983) in Australia. Although there are places where seagrass loss has been reversed following improvements in water quality, such as Tampa Bay, North America (Tomasko et al. 2005), and Hervey Bay, Australia (Preen and Marsh 1995), the number of declines far exceeds the reported increases, leading to the concern that seagrasses are experiencing a global crisis (table 1; Short and Wyllie-Echeverria 1996, Duarte 1999, 2002, Green and Short 2003).

Multiple stressors behind seagrass declines

Environmental, biological, and extreme climatological events have been identified as causes of seagrass losses in temperate and tropical regions (table 1). Threats from global climate change (e.g., increases in sea surface temperature, sea level, and frequency and intensity of storms and associated surge and swells), from regional shifts in water quality (e.g., in the Chesapeake Bay; Kemp et al. 2005), and from more localized impacts due to increased loading of sediment, contaminants, and nutrients (figure 6a) reaching coastal environments (e.g., Cockburn Sound; Walker et al. 2006) have had demonstrable impacts on the health of seagrass-dominated coastal ecosystems worldwide (table 1). These global, regional, and local stressors can all independently result in large-scale seagrass loss; however, seagrasses are often simultaneously influenced by multiple stressors at different temporal and spatial scales, and studies that examine the interacting impacts of multiple stressors are lacking. In all regions, the environmental effects of excess nutrients or sediments are the most common and significant causes of seagrass decline, and result in small to very large areas of seagrass being lost. The direct influence of other organisms (e.g., brown tides, urchin overgrazing, and disease) has also led to large-scale losses and, when acting in concert with suspended sediments and nutrients, can accelerate the trajectory of seagrass loss for the area in question. The greater diversity of causes attributed to seagrass declines in temperate regions most likely reflects the much greater research and monitoring effort in Europe, North America, and southern Australia (Duarte 1999), rather than greater susceptibility in these regions (table 1).

Extreme climatic events (e.g., hurricanes, tsunamis) also can have large-scale impacts on seagrass communities and subsequent effects on the ecosystem services provided by seagrass meadows (table 1, figure 4). In the case of the pulsed turbidity events following the passage of tropical storms in Hervey Bay, Australia, which resulted in 1000 km^2 of seagrass loss, high mortality and emigration of dugong eventually occurred (Preen and Marsh 1995). Recently, greater attention has focused on the role of top-down control in seagrass declines, as cascading effects on trophic dynamics follow the loss of higher-level consumers in seagrasses and other ecosystems (Heck et al. 2000, Jackson et al. 2001). Thus, seagrasses are being influenced by both bottom-up and top-down processes (Heck and Orth 2006). Although our primary focus here is on the seagrasses themselves, seagrass-associated species are also threatened or vulnerable to extinction. Eleven of 28 fish

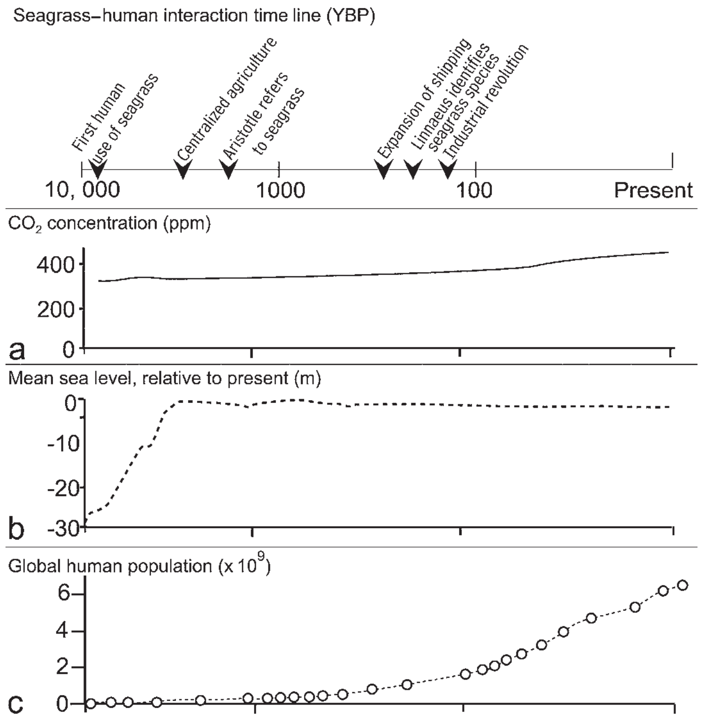

Figure 5. Seagrass–human interaction time line for the past 10,000 years, showing (a) carbon dioxide (CO_2) concentrations (Thoning et al. 1989, Petit et al. 1999), (b) mean sea level (Fleming et al. 1998), and (c) global human population (Cohen et al. 1995). Abbreviations: m, meters; ppm, parts per million; YBP, years before the present.

Table 1. A synthesis of 47 representative case studies of seagrass loss.

Area lost (km^2)	Major mechanisms of loss (number of reports): Environmental	Biological	Extreme events
Temperate region			
< 1.0	Dredging, hydrological, dune migration (7)	Herbivory, introduced species, bioturbation (7)	Ice scour, heat waves (2)
1.0–100	Eutrophication, sediment deposition (4)	Brown tide (1)	No data
> 100	Eutrophication, sea-level rise, high temperature (5)	Wasting disease (1)	No data
Tropical region			
< 1.0	Vessel grounding, thermal pollution (5)	Herbivory (3)	No data
1.0–100	Eutrophication, boating, sedimentation (6)	Brown tide, urchin herbivory (2)	No data
> 100	Hydrological, sediment resuspension (3)	No data	Pulsed turbidity (1)

Note: The seagrass genera studied in temperate regions include *Cymodocea, Halodule, Heterozostera/Zostera, Posidonia, Syringodium,* and *Thalassia;* genera studied in tropical regions include *Halodule, Halophila, Syringodium, Thalassia,* and *Zostera.* An expanded table detailing the results of each study can be found at *www.vims.edu/bio/sav/bioscience_global_crisis_table_1.pdf.*

species vulnerable to extinction in the United States use seagrass habitat during at least part of their life cycle (Musick et al. 2000).

In addition to the well-documented causes of seagrass declines, other threats to these species are emerging. Over the last 20 years, introductions of nonnative marine species have arisen as a major environmental challenge for the world's oceans (Carlton 1989). Such introductions are accelerating worldwide (Ruiz et al. 2000), a trend that will continue as the pathways for introductions widen and proliferate and as intervention lags (figure 6b; Naylor et al. 2001, Levine and D'Antonio 2003, Padilla and Williams 2004). At least 28 nonnative species have become established in seagrass beds worldwide, of which 64% have documented or inferred negative effects (figure 6b). The concern about this emerging threat to seagrass beds is that, whereas it is possible to reverse eutrophication or cease dredge-and-fill activities, it is virtually impossible to remove a nonnative species after establishment and spread (Lodge et al. 2006). Lastly, the rapid expansion of fish farming and other aquaculture practices (e.g., shellfish culture) can have serious consequences on local populations of seagrasses through physical disturbance or increased deposition of organic matter and nutrients (Marbà et al. 2006).

Seagrass monitoring, management, protection, and restoration

Reported cases of seagrass loss have increased almost tenfold over the last 40 years in both tropical and temperate regions (figure 6c), suggesting increased rates of seagrass decline worldwide. In response to seagrass loss caused by increasing anthropogenic stresses on coastal seagrass meadows, during the last decade there has been a major increase in the number of marine protected areas that include seagrass (figure 6d) and in seagrass monitoring (figure 6e) and restoration projects throughout the world. The current challenges are to synthesize this information to enhance our understanding of global seagrass processes, threats, and change, and to apply this knowledge to develop effective resource management programs. Efforts to protect seagrasses now include 19 monitoring programs that encompass 30 seagrass species in 44 countries (approximately 2000 sites).

Perhaps the most difficult issue facing resource managers as they try to protect seagrasses is in implementing management plans to reduce nutrients and sediments from both diffuse and point sources in surrounding watersheds, especially where watersheds cross jurisdictional boundaries. Seagrass distribution and abundance are being successfully incorporated into water quality management programs and environmental impact studies in several areas, notably the Chesapeake Bay and Florida in North America, and Moreton Bay and the Great Barrier Reef Marine Park in Australia (Kenworthy et al. 2006). Management applications are based on the foundation of seagrass knowledge developed in each of those areas and are aimed at establishing water quality standards to conserve and restore seagrasses (Dennison et al. 1993, Coles and Fortes 2001, Kenworthy et al. 2006).

A number of seagrass management plans have objectives with quantitative

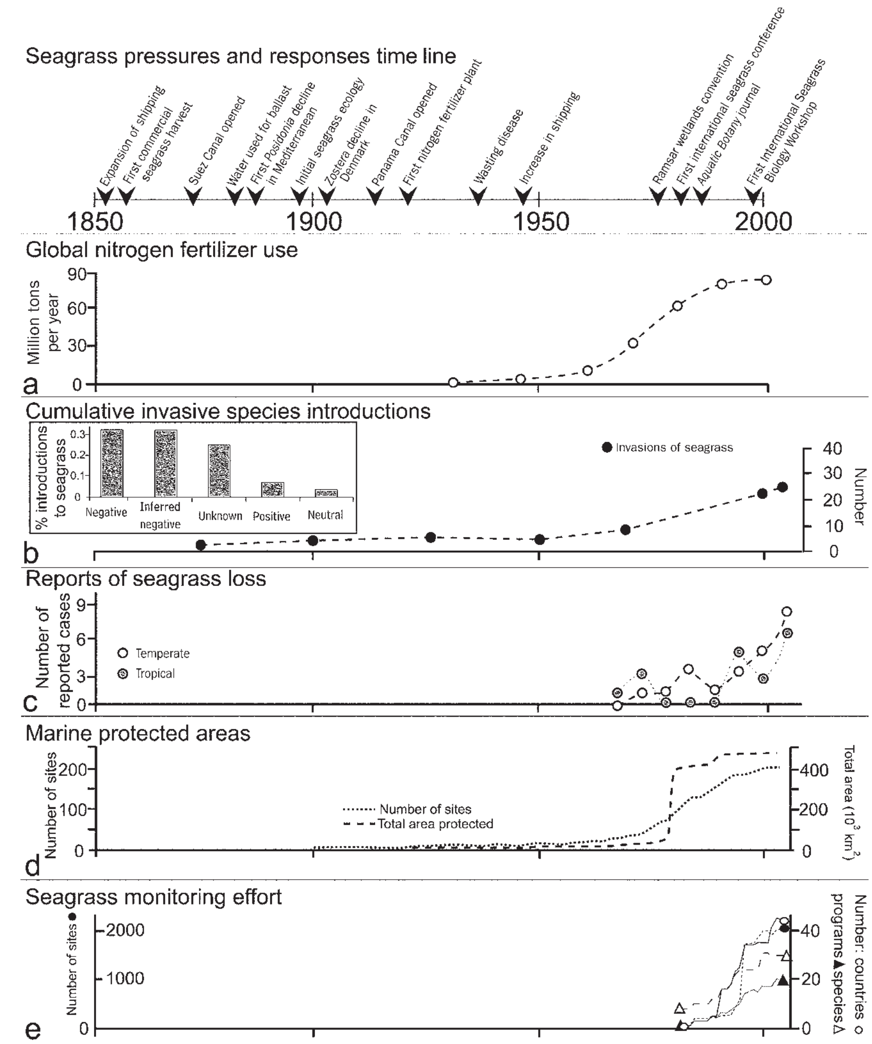

Figure 6. Time line showing pressures on seagrass populations and responses over the last 150 years, including (a) nitrogen fertilizer use (Frink et al. 1999), (b) species introduced to the marine environment (Ruiz et al. 2000), (c) reported cases of seagrass loss in both tropical and temperate regions since 1965, (d) marine protected areas (based on Spalding et al. 2003), and (e) monitoring effort (Duarte et al. 2004).

metrics aimed at restoring seagrass to target levels that allow resource managers, who are making critical decisions, to expend public funds. One key example is the process of seagrass restoration, for which costs are very high (Kenworthy et al. 2006) and success is uncertain. Worldwide, the success of seagrass transplantation and restoration is around 30% (Fonseca et al. 1998), although in some regions higher success rates have been reported (Green and Short 2003). Numerous restoration projects have been attempted or are being planned at mostly small scales (< 1 ha) using a variety of techniques with both adult plants and seeds, although interest in larger-scale transplant programs is growing as resource managers become more aware of the value of seagrass and develop mitigation programs to offset losses from activities such as dredging (Fonseca et al. 1998). However, some species are so difficult to transplant that restoration is not logistically or economically feasible, and longer-term studies that compare the functioning of transplanted areas with that of natural systems are rare (Fonseca et al. 1998).

Seagrass loss is usually the symptom of a larger problem. To effectively reverse the decline of seagrasses, conservation plans must first identify and resolve the problems at a scale that includes the interconnectivity of coastal systems and the mechanisms affecting the declines and gains (e.g., water quality, land use practices). Once this is done, restoration efforts should be balanced against the capacity of seagrasses to recover naturally. Strategic restoration can introduce founder populations that can accelerate the overall recovery of the ecosystem (Orth et al. 2006). At present, our knowledge of the population dynamics of seagrasses remains poor for the majority of species and regions (Kenworthy 2000). As a result, considerable research efforts will be required to guide effective restoration and preserve genetic diversity (Williams 2001). Better ecological information on such approaches is required, and especially the trajectories on how rapidly ecosystem services are restored. Until this is achieved, management efforts should be aimed at systemwide approaches to protect these ecosystems.

Science and public awareness of seagrasses: A disconnect

Over the last 35 years, scientists have responded to the need for more information on seagrasses and their contribution to the productivity of coastal and estuarine systems with more research and monitoring programs that have resulted in a 100-fold increase in the annual number of papers published during this time period. This increase represents a sustained publication growth rate of 12.8% per year (figure 7a) and includes a seagrass atlas (Green and Short 2003), a methods book (Short and Coles 2001), and two research syntheses (Hemminga and Duarte 2000, Larkum et al. 2006).

Despite the increase in scientific publications on seagrasses, the level of public awareness, as reflected by the number of reports on seagrass ecosystems in the media, is far less than that for other coastal habitats. Salt marshes, mangroves, and coral reefs receive 3-fold to 100-fold more media attention than seagrass ecosystems, although the services provided by seagrasses, together with algal beds, deliver a value at least twice as high as the next most valuable habitat (figure 7b; Costanza et al. 1997). This difference in media attention partly reflects disproportionate research effort, as the number of scientific documents on seagrass is also below those on salt marshes, mangroves, and coral reefs (figure 7b). Reports on seagrasses in the *New York Times* and *National Geographic* are 3 to 50 times lower than those for salt marshes, mangroves, and coral reefs. Nevertheless, these data indicate that translating scientific understanding of seagrass ecosystems into public awareness has not been as effective as for other coastal ecosystems.

Much of this disconnect between available information and public awareness undoubtedly stems from the invisibility of seagrasses, as they grow underwater, and from the avoidance

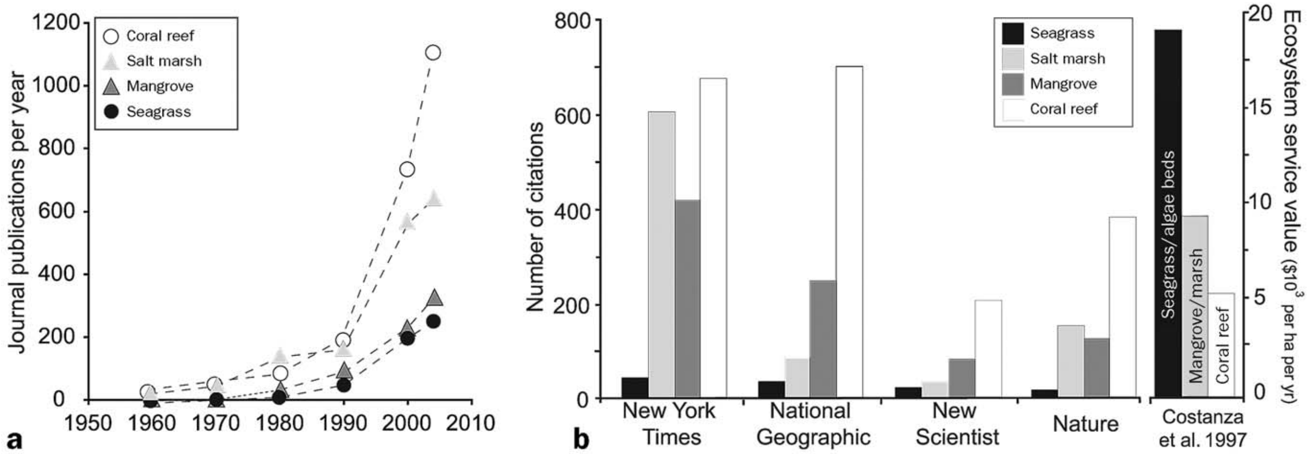

Figure 7. Comparison of seagrass, salt marsh, mangrove, and coral reef habitats in terms of (a) journal publications (Web of Science 1950–2006) and (b) citations in more broadly accessed media (Google and Web of Science), and estimated monetary value of ecosystem services provided by these habitats (Costanza et al. 1997).

of their very shallow habitat by many boaters (unless they run aground, whereupon the boat propellers damage seagrass). In addition, although a high diversity and abundance of organisms live in seagrass beds, the animals are often small and cryptic, in contrast to the large and dazzling organisms that attract the general public to coral reefs. The few charismatic megafauna that do inhabit seagrass meadows (manatees, dugongs, and sea turtles; figure 1) are elusive and not easily viewed in the wild, and because they are endangered by overharvesting and habitat destruction, they are not nearly as abundant as the fish and invertebrates on coral reefs (Jackson et al. 2001). Without strong public support for seagrasses and the uncharismatic but highly productive animals they shelter, conservation efforts will continue to lag behind those of other key coastal ecosystems.

The need for a global conservation effort for seagrasses

We have presented the case that seagrasses are facing a crisis due to a diverse array of pressures from human activities in the coastal zone, as well as the increased frequency and intensity of natural disasters such as hurricanes, which may also be indirectly associated with human activities (i.e., global warming). Although seagrasses have experienced considerable environmental changes in sea level, CO_2, and temperature over the past 100 million years of their evolutionary history, these historical changes were gradual. How well seagrasses can adapt to the unprecedented rates of change they are currently experiencing is unknown. In view of the many cases of documented seagrass loss, predictions for the future of seagrass-dominated coastal systems cannot be optimistic.

While the global science community has focused on predicting future change to the oceans and to coastal ecosystems for iconic groups like corals, seagrasses have generally been ignored by all but marine scientists, except in the most highly developed countries. Given the importance of seagrasses to humans (Costanza et al. 1997, Larkum et al. 2006), it is imperative to assess the future of seagrasses under the exponentially increasing pressures of human growth and development in the watersheds and coastal zones of the world. A quantitative analysis of seagrass trajectories could form the foundation to incorporate seagrasses into a global science policy for the world's oceans.

Monitoring seagrass meadows is a necessary but insufficient conservation activity, because remedial actions are not fully effective in stopping declines once they are detected (Short and Burdick 1996, Delgado et al. 1999). It will be critically important to forecast the likely cumulative effects of the known and emerging stressors of seagrasses. Present scenarios for future seagrass trends are either of limited geographic extent (Fourqurean et al. 2003) or limited to qualitative statements (Short and Neckles 1999, Duarte 2002, Duarte et al. forthcoming). Quantitative forecasts, together with risk analysis identifying the most vulnerable areas, can inform conservation and management strategies and help determine the most cost-effective allocation of resources to conserve seagrass ecosystems. Furthermore, developing models that incorporate the landscape scale of seagrass dynamics and can link to watershed runoff models will help inform resource managers about the consequences of various watershed activities on seagrass dynamics.

Our major recommendation is to respond to the global seagrass crisis with extensive conservation efforts involving comprehensive nutrient management schemes, sanctuaries or protected areas, and education for the public and resource managers (Kenworthy et al. 2006). The majority of seagrass losses are a result of human activities in the adjacent watersheds, which lead to increased nutrient and sediment runoff. The isolated case studies of seagrass recoveries when inputs of nutrients (e.g., Tampa Bay, Florida; Tomasko et al. 2005) or sediments (Hervey Bay, Australia; Preen and Marsh 1995) are curtailed demonstrate the potential effectiveness of conservation efforts. The preservation of seagrasses and their associated ecosystem services—in particular, biodiversity, primary and secondary production, nursery habitat, and nutrient and sediment sequestration—should be a global priority. We believe that the crisis facing seagrass ecosystems can be averted with a global conservation effort, and this effort will benefit not just seagrasses and their associated organisms but also the entirety of coastal ecosystems.

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