Gordon W. Thayer
Douglas A. Wolfe
Richard B. Williams

The Impact of Man on Seagrass Systems

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Seagrasses must be considered in terms of their interaction with the other sources of primary production that support the estuarine trophic structure before their significance can be fully appreciated

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Twelve genera of aquatic angiosperms are completely adapted to the marine environment, having a well-developed anchoring system and the ability to function normally and complete the generative cycle when fully submerged in a saline medium (den Hartog 1970). These seagrasses, which are widespread throughout the world, rank among the most productive systems in the ocean and constitute one of the most conspicuous and common coastal ecosystem types. Eelgrass, *Zostera marina*, one of these flowering seagrasses, supports characteristic floral and faunal assemblages and forms consistent and recognizable communities or ecosystems—regardless of the particular geographic location or species structure (Fig. 1).

Because of their shallow sublittoral and to some extent intertidal existence, seagrass systems are subject to stresses imposed by man's ever-growing use of the coastal zone. Our continued multiplicity of demands upon estuarine and coastal environments as producers of food, avenues of transportation, receptacles of wastes, living space, and sources of recreational or esthetic pleasure makes it imperative that we understand the functioning of these near-shore ecosystems. This knowledge is essential to enable proper evaluation of the respective roles of the various ecological components of the system, so that we can manage this environment wisely and derive the maximum benefits from each of the components.

The true importance of seagrass meadows to coastal marine ecosystems is not fully understood and is generally underestimated. The scientific literature on seagrass systems is extensive, and this paper makes no pretense of a complete review. Rather, what is attempted here is a brief and concise evaluation, on the basis of existing information, of the probable value of seagrass communities to man's total ecosystem and the impact of man's varied activities upon seagrass communities, with special reference to *Zostera marina* communities. For comprehensive reviews of seagrasses and research on these systems see den Hartog (1970), Zieman (1970), McRoy (1973), and Phillips (1974).

It is in the context of the total estuarine system that man's impact upon seagrass communities must be evaluated. The ways that eelgrass acts to affect the function of estuarine ecosystems may be summarized according to the scheme established by Wood, Odum, and Zieman (1969) for seagrasses in general:

1. Eelgrass has a high growth rate, producing on the average about 300-600 g dry weight/m^2/year, not including root production.

2. The leaves support large numbers of epiphytic organisms, with a total biomass perhaps approaching that of the grass itself.

3. Although a few organisms may feed directly on the eelgrass and several may graze on the epiphytes, the major food chains are based on eelgrass detritus and its resident microbes.

4. The organic matter in the detritus and in decaying roots initiates sulfate reduction and maintains an active sulfur cycle.

5. The roots bind the sediments together, and, with the protection afforded by the leaves, surface erosion is reduced, thereby preserving the microbial flora of the sediment and the sediment-water interface.

6. The leaves retard currents and

Gordon W. Thayer, Leader of the Ecosystems Structure and Function Task of the Ecology Division at the Atlantic Estuarine Fisheries Center, NMFS, NOAA, Beaufort, N.C., received his Ph.D. in zoology in 1969 from North Carolina State University. His research interests include phytoplankton and nutrient relations, zooplankton larval fish dynamics, and food-web dynamics of estuarine and coastal ecosystems with emphasis on benthic and seagrass systems.
Douglas A. Wolfe, Director of the Ecology Division at AEFC, received his Ph.D. in physiological chemistry in 1964 from Ohio State University. His research interests span the fields of malacology, fatty acid biochemistry, radioecology, and trace metal dynamics and modeling in estuarine and coastal ecosystems. Both he and Dr. Thayer are adjunct associate professors at North Carolina State University.
Richard B. Williams is the Director of the Biological Oceanography Program of the National Science Foundation. He received his Ph.D. from Harvard in 1962 and was Leader of the Ecosystems Task at AEFC until 1972. His research interests have been in the fields of phytoplankton, marine angiosperm, and zooplankton ecology and radioecology. He has recently written several articles on computer modeling of ecological systems. *This manuscript was supported through a cooperative agreement between the National Marine Fisheries Service and the U.S. Atomic Energy Commission.* *Requests for reprints should be sent to Dr. Thayer, Atlantic Estuarine Fisheries Center, Beaufort, NC 28516.*

Figure 1. Beds of the temperate seagrass *Zostera marina* (eelgrass) in the Newport River estuary, Beaufort, N.C., stabilize the sediment and provide protection and food for a vast variety of invertebrates, fish, and shore birds. (Photo by Herb Gordy, AEFC.)

increase sedimentation of organic and inorganic materials around the plants.

7. Eelgrass absorbs phosphorus both through the leaves and the roots; it may be that the phosphorus absorbed through the roots is released through the leaves, thereby returning phosphate from sediments to the water column (McRoy and Barsdate 1970). Nitrogen also is taken up by the roots and transferred to the leaves and into the medium (McRoy and Goering 1974).

In addition to these intricate ecological functions, dried eelgrass leaves have been used by man as fuel, packing and upholstering material, insulation, fodder, and fertilizer, but the manufacture and use of eelgrass products have been local and intermittent.

Temperate eelgrass communities

Eelgrass occurs throughout the Northern Hemisphere in temperate marine coastal waters and is very important to the trophic function and overall productivity of the coastal zone. On the Pacific coast eelgrass communities are found from Port Clarence, Alaska, to Agiopampo Lagoon, Mexico (Phillips 1972); on the Atlantic coast eelgrass extends from Greenland to Cape Fear, N.C. *Zostera* is abundant along the English coastline, the Danish coastline, the Spanish coastline, along the northern Mediterranean coast into the Black Sea, in the Baltic and White Seas, and along much of the coastlines of the Yellow Sea and Sea of Japan. Den Hartog (1970) and Phillips (1972) have described the distribution of this species outside North America, and den Hartog noted that, although eelgrass probably is the best known of the marine angiosperms, there are only a small number of thorough studies on its ecology.

Eelgrass tolerates for brief exposures a wide range of salinities and temperatures—from about 10–40 ‰ (parts per thousand) and 0–40°C. Conditions conducive for growth and reproduction, however, are probably restricted to 10–30 ‰ and 10–20°C. The plant flowers only when the temperature is above 9–15°C, and seed germination is optimal at salinities of 4.5–9 ‰ (Arasaki 1950; Phillips 1974). Arasaki, however, noted that a salinity range of 23–31 ‰ is optimal for vegetative growth of eelgrass in Japan. All studies to date appear to be merely descriptive rather than experimental, and interactions of temperature and salinity have not been evaluated. Zieman (1970) has suggested that there is a temperature–salinity interaction for *Thalassia testudinum*, a tropical seagrass commonly called turtle grass (see Fig. 2). His work has shown that *Thalassia* is able to tolerate low salinities at low environmental temperatures but is unable to withstand low salinities when water temperatures are high. This also may be true for *Zostera* and other seagrasses. The effect of photoperiod has not been determined in conjunction with temperature and salinity.

The depth distribution of seagrasses depends upon a complex of interrelated ecological considerations: depth, waves, currents, substrate, turbidity, and light penetration. Mean low water is a realistic effective upper limit for most seagrasses regardless of other factors, but the lower limit is probably established by a combination of minimum light intensity required for growth and presence of suitable substrate: seagrasses may grow at 20–30 meters depth in clear water but be restricted to depths of less than one meter where wave action continually stirs up the bottom, producing high turbidity. Seagrasses can be found on many substrates, from coarse sand to almost liquid mud, but the normal substrate is a mixture of mud and sand in which a reducing environment prevails beneath the oxidized sediment surface. McRoy (1973) and Phillips (1974) have indicated that much more research is necessary on substrates, since it appears that seagrasses condition the substrate and become an integral part of it. Alteration of the substrate may render it unfit for continued colonization by seagrasses.

Productivity of seagrass systems has been widely measured, especially that of *Zostera marina* and *Thalassia testudinum* communities. Values for annual production of *Thalassia* range from 200 gC (grams of carbon) per m² to 3,000 gC/m², and annual values for *Zostera* range from about 5–600 gC/m² (Phillips 1974). Representative annual production values for eelgrass are 331 g dry weight/m² for Puget Sound, Wash. (Phillips 1974), and 10–58 g dry weight/m² for Great Pond, Mass. (Conover 1958). Recent studies at Beaufort, N.C. (near the southern edge of *Zostera*'s range on the Atlantic coast), indicate mean annual production of about 340 gC/m² or about 690 g dry weight/m² (Dillon 1971). Associated with the *Zostera* in these grass beds are *Halodule* and *Ectocarpus*, which together contribute an additional 300 gC/m² annually (Dillon 1971).

Thus, on an areal basis, *Thalassia* and *Zostera* beds are more productive than the world averages for cultivated corn (412 gC/m²) or rice (497 gC/m²) or the U.S. average for hay fields (420 gC/m²) or tall-grass prairie (446 gC/m²) (Odum 1959). These seagrass production rates are higher, on an areal basis, than phytoplankton production in upwelling areas off Peru (Ryther 1969), one of the most productive sea areas in the world. Seagrass production is supplemented in these communities, or in estuaries in general, by the production of benthic microalgae, macroalgae, epiphytes, phytoplankton, and shore-based vegetation such as salt marsh.

Petersen (1918) recognized the importance of eelgrass to ecosystem function over half a century ago, when he attempted to synthesize a model of the trophic relations of the Kattegat region of Denmark. His calculations were made from available estimates of fisheries productivity, gut content analyses, data on the occurrence of other organisms, and, where necessary, an assumed 10% relationship between standing crops of succeeding trophic levels (see Fig. 3). The assumed conversion efficiency was not rigorously examined, nor were the standing crops of all species actually measured, and, most important, secondary production of the lower trophic levels and primary productivity of the plant component (though discussed and recognized as significant) were either not measured or not employed in the

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Figure 2. Tropical turtle grass, *Thalassia testudinum*, in Puerto Rico offers shelter and food for sea urchins, *Diadema antillarum*, four-eye butterfly fish, *Chaetodon capistratus*, and tomtate (small striped fish), *Haemulon aurolineatum*. (Photo by Douglas Wolfe, AEPD.)

calculations. Nonetheless, Petersen's calculations suggested that cod and plaice were dependent upon the *Zostera* community for food resources. Petersen's model was tested in the 1930s when there was a sudden decrease in *Zostera* abundance throughout much of its geographic range. Although this drastic decline did not result in as great a decrease in bottom fishes in the North Atlantic as would have been predicted from Petersen's calculations, Milne and Milne (1951, p. 55) stated that undoubtedly the eelgrass catastrophe caused a major decline in these fishes.

Since [illegible] Atlantic [illegible] Fisheries Center have [illegible] dynamics [illegible] eelgrass [illegible] N.C. [illegible] summarized in Figure [illegible] cated that the [illegible] mals collected [illegible] and det[illegible]

likely produced within the bed or at least entrained within the bed (Adams 1974; Thayer et al., in press). Further, their data suggest that for the macrofaunal community (epifauna, infauna, and fish) about 12% of the food energy consumed by the organisms is utilized for the production of their new tissue; the remaining food energy consumed is either excreted or lost through metabolic processes.

Marshall [illegible] noted that approximately two-thirds to three-fourths of the *Zostera* [illegible] the sediment annually [illegible] southern New England [illegible] algae contribute [illegible] detritus. Thayer et al. [illegible] plant [illegible] North [illegible] supplying [illegible] from [illegible]

vertebrates and fishes than the adjacent estuary.

Of special importance is the recognition that, although the eelgrass community represents a distinct faunal assemblage, it is still only part of the overall estuarine system and the primary production of [illegible] benthic [illegible] and shoreline [illegible] the [illegible] but the faunal assemblages in other estuarine habitats as well (Fig. 5). Williams (1973) has estimated that in the [illegible] estuarine system [illegible] other [illegible] of the estuarine [illegible] [illegible] Fig. [illegible] and Mundell [illegible]

estimated that benthic microalgae account for about 6 $gC/m^2/yr$, or only 3% of the total, with the percent contribution to the total of other sources being only slightly reduced. We have no information on organic production by macroalgae and the availability of dissolved organic material.

The detrital material which is exported from the grass beds probably is significant to the trophic function of estuarine complexes. Further, fishery organisms from this estuarine system utilize most of the primary productivity, based on best available estimates of trophic structure and efficiency (P. B. Williams, unpubl.). By far the predominant trophic pathway in this estuarine system is eelgrass (plus algae and *Spartina*) → detritus (including its associated microbial community) → herbivores → carnivores.

Environmental influences

Despite the extensive studies on seagrass productivity and on the temporal and spatial variability in biological composition of seagrass communities, little is known of the general principles of ecosystem function and the factors controlling the "ecological success" of the community. As a result, subtle changes which may be caused by human activities generally pass unnoticed or are ascribed to "natural variation," and only gross changes, such as total destruction of a bed, are described in the literature. Even then, direct causal relationships are not always established.

The species diversity of the community, together with temporal and spatial variation of biomass, render the seagrass community itself difficult to describe. When this dynamic community is considered as an integral part of the larger, complex estuarine ecosystem to which it belongs, it is not easy to design and carry out sampling programs adequate to define the effects of man's activities. Until recently, the need for such elaborate ecological research was not recognized.

Of the several human activities which affect, or can be inferred to affect, success of seagrass communities in estuarine and coastal ecosystems, only a few have so far been documented as actually being deleterious. In general, dredging and other disturbances of the bottom sediments or sedimentation rates can destroy several seagrass species. Additions of toxic materials have been shown to affect animal components of seagrass communities but not the seagrass itself; thermal wastes have been shown to affect both the animal components and, in the case of *Thalassia*, the grass itself. Commercial fishing on seagrass bottoms, like dredging, can disrupt the growth of the plants. Although commercial harvesting of seagrasses is obviously an important influence, discussions of harvesting generally are concerned with production and profits, not with effects on the resource. All the potentially deleterious effects directly result from uncontrolled development in the coastal zone to satisfy the increasing needs of an expanding human population with an internally perpetuating value system originally developed under radically different ecological and technological constraints.

All seagrass beds appear to overlie anaerobic sediments. Thus dredging not only increases suspended material and accelerates sediment deposition but also causes changes in the redox potential of the sediment. Under these conditions eelgrass density may be reduced considerably. It is not known whether the reduction is caused by direct smothering of the grass, by decrease in available light due to increased turbidity, by a change in the redox potential of the surface sediment by rapid addition of oxidized materials, or by toxins released from the suspended sediments.

Odum (1963) studied the ecological effects of dredging on *Thalassia* and *Diplanthera (Halodule)* beds. During dredging, light penetration was much reduced and the productivity and chlorophyll content of the grasses diminished. During the fol-

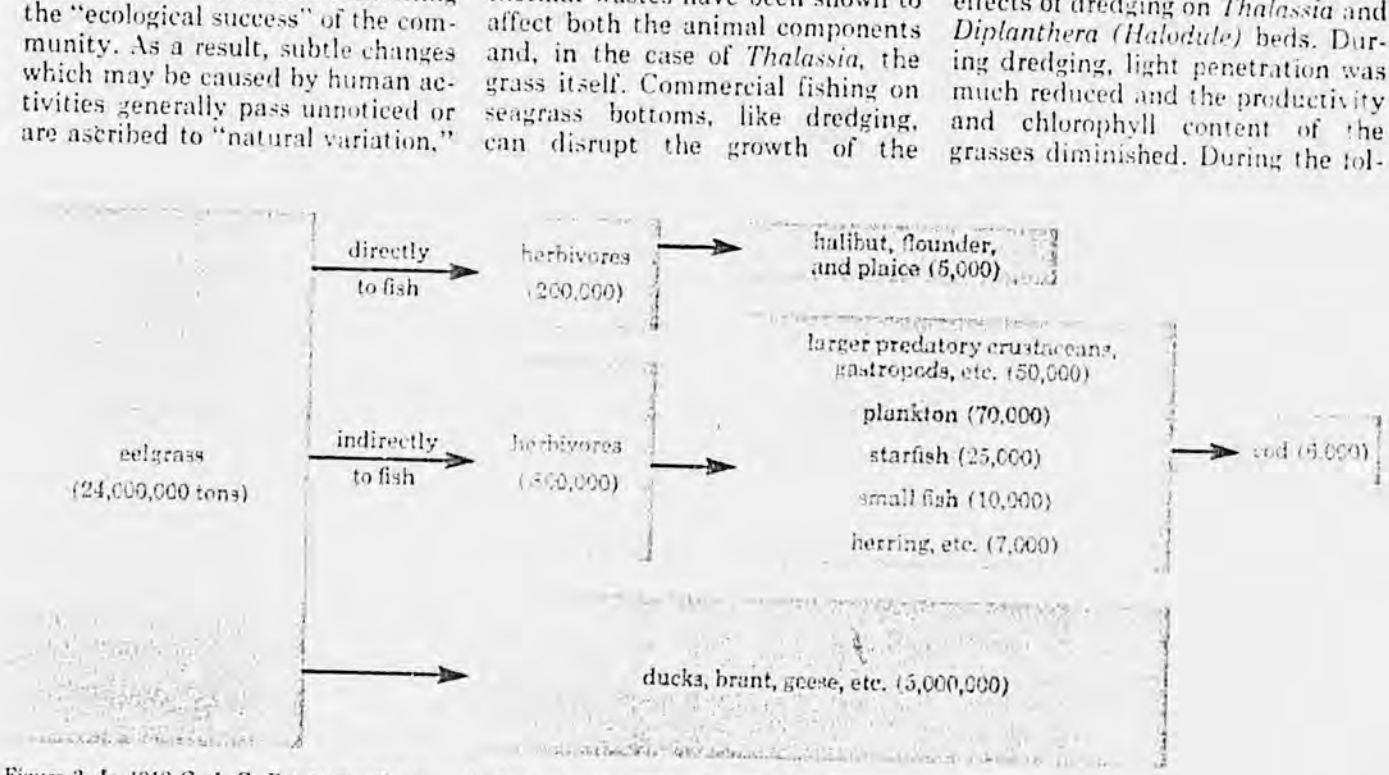


Figure 3. In 1918 C. J. G. Petersen estimated the relationship among standing crops of organisms supported by the eelgrass system in Denmark. Herbivores used *directly* as food for larger forms are small herbivorous animals eaten directly by the food fish such as halibut, flounder, and plaice; those used *indirectly* are consumed by crustaceans, small fish, etc., which in turn are utilized by food fish such as cod. Tons are nonmetric. (Data from Petersen 1918 and Milne and Milne 1951.)

lowing growing season, in areas not smothered by silt, however, plant production and chlorophyll content were greater than during the predredging and dredging periods. The enhanced growth was attributed to redistribution of dredge spoil and, thus, possible increased availability of mineral nutrients.

Wood (1959) found that after removal of *Zostera* the bottom sediment became oxidized, and recovery of eelgrass was impaired. Odum (1963) noted that *Thalassia* was killed when buried beneath 30 cm of dredge spoil in Redfish Bay, Texas. Small *Zostera* areas cleared by hand, however, recovered completely within one season (Marshall and Lukas 1970). Briggs and O'Connor (1971) found that areas of Long Island Sound which had been used for deposition of dredge spoils lacked vegetation, especially eelgrass, though it was abundant at nearby sites where the bottom was undisturbed.

Clearing agricultural lands and channeling streams, thereby increasing the rate of erosion and thus causing high inputs of sediment into estuaries and coastal areas, might have effects on eelgrass similar to those noted for dredging. Stream diversion, on the other hand, would decrease input of freshwater and suspended sediments, with the probable net effect of increasing water clarity and promoting upstream penetration of saline waters. This might enhance the establishment of eelgrass over a wider area but, in other instances, might decrease the distribution of other species. For example, manatee grass, *Syringodium filiforme*, is found in Anclote Anchorage, Florida, only in areas where there are significant amounts of freshwater runoff.

The potential deleterious effect of freshwater diversion lies not only in decreased salinities but also in the accompanying diversion of mineral nutrients—nitrogen and phosphorus—usually introduced into estuaries in the freshwater runoff. Similarly, stream channelization promotes runoff and thereby decreases retention of detritus and valuable mineral nutrients, both in the agricultural lands of the coastal zone and in the recipient estuaries.

The addition of waste materials to estuarine ecosystems usually impinges more directly upon the animal components than upon the primary producers. The effects of pesticides and chlorinated hydrocarbons (Risebrough 1971), heavy metals (Merlini 1971), and petroleum derivatives (Radcliffe and Murphy 1969) have been well documented for many types of marine organisms, but their direct effects on eelgrass or other seagrasses are generally unknown. Studies by Parker (1962, 1966) have shown that sediments and *Thalassia* constitute the prime reservoirs for isotopes added to the system and that there can be a rapid flux between these two system constituents. Likewise, dissolved copper is removed from the overlying water by either the sediment or *Zostera* (Barsdate, Nebert, and McRoy, in press).

Other environmental disturbances

Spillage of crude oil from ship traffic in the English Channel was implicated as the cause of widespread reduction of eelgrass in England in the early 1930s (Duncan 1933), but a direct causal relationship was not established. On the south coast of Puerto Rico, however, oil spillage was shown to produce lasting damage to the tropical seagrass *Thalassia* (Diaz-Piferrer 1962). The role of seagrasses or their detritus in accumulating pesticides, PCBs, heavy metals, or petroleum derivatives and transferring these pollutants to other, more sensitive trophic levels has not been investigated, and literature showing other direct effects on seagrasses could not be found. Since eelgrass is capable of anaerobic respiration (McRoy 1966), direct effects of municipal organic wastes, other than those of sludge deposition, may be negligible initially. However, the length of time the plant can tolerate anoxic conditions is not known, especially under the decreased light penetration that may accompany discharge of sewage.

Since most seagrass [illegible] and seasonal [illegible] in productivity are [illegible] which are in part related to water temperatures, thermal pollution can have a critical effect. Numerous investigators (see Zieman 1970) have found that *Thalassia* production shows a strong temperature dependency between 23–29°C and declines rapidly above 30° and below 20°. Data collected by Setchell (1929) from Mt. Desert Isle, Maine, suggest that 5–17° is the normal temperature range for *Zostera* and that above 20° it undergoes heat rigor. Dillon's studies (1971), however, indicate that near its southern boundary (Beaufort, N.C.) the upper temperature limit for *Zostera* is more nearly 30° and that temperatures above this are lethal to the plant. Thayer et al. (in press) have indicated that *Zostera* in the Newport River estuary near Beaufort began to die off when the temperature reached approximately 28° in August. Thus, there are upper and lower tolerance limits beyond which seagrasses may be destroyed, and their thermal limits may differ between north temperate and south temperate regions.

Discharges of heated water, though not documented for *Zostera*, are known to destroy tropical seagrass beds. At Turkey Point, in Biscayne Bay, Fla., *Thalassia* disappeared seasonally from the immediate vicinity of the thermal plume at the mouth of the discharge canal of the power station (Zieman 1970); there was also a loss of invertebrate fauna associated with the beds. Kolehmainen, Martin, and Schroeder (in press) have recorded decreased biomass of *Thalassia* in the area of the thermal plume issuing from a fossil-fuel power-generating plant in Guayanilla Bay, Puerto Rico, but were unable to determine whether this decrease resulted from elevated temperatures or increased scouring. Phillips (1974) warns that heated water released into eelgrass habitats could disrupt the reproductive cycle of *Zostera*, presumably interfering with the normal temperature-dependent periodicity of flowering and germination.

Effects of ionizing radiation are unknown, since background radiation levels have not been increased significantly in the environment, except perhaps at the Pacific Proving Grounds, where the effects of elevated radiation were overpowered and overshadowed by the effects of blast and massive sedimentation. As mentioned earlier, Parker (1962, 1966) has indicated that *Thalassia*

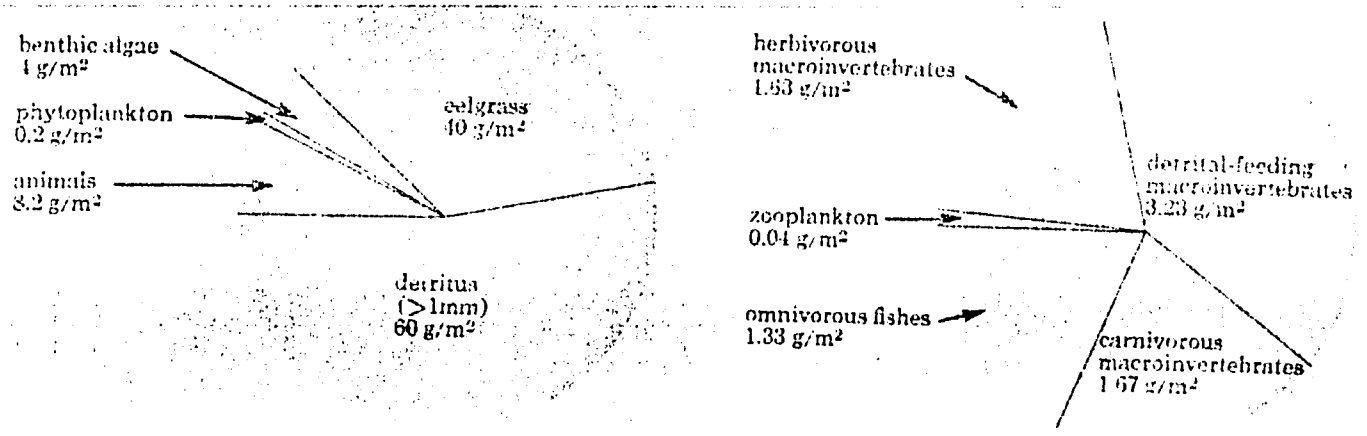


Figure 4. *Left:* Relation among standing crops and detritus in a 20,000 square meter eelgrass bed in the Newport River estuary, Beaufort, N.C. *Right:* Standing crops of animals in the eelgrass bed. Plants and detritus are in dry weights; animals in ash-free dry weight. (Data from Thayer et al., in press.)

takes up radionuclides, but seagrasses accumulate radioisotopes only to low levels (Polikarpov 1966), and the major role of seagrasses would be in conveying radioisotopes to other organisms in the community. Again, the efficiencies of these food-chain transfers simply are not yet known.

The activities of commercial fishermen using bottom trawls in the bays, sounds, and estuaries frequently conflict with the success of eelgrass and, consequently, of bay scallops. In North Carolina, where bay scallops generally occur in conjunction with eelgrass, scallops are usually harvested by bar dredges (25 kg maximum dredge weight) and hand rakes. Both methods uproot the grass, but dredging does so over large areas. Not only is the grass uprooted but the bottom sediments are stirred up, promoting oxidation of the sediments so that recolonization of *Zostera*—and bay scallops—probably is impeded (Thayer and Stuart 1974). On the Pacific coast, eelgrass renders oyster harvest difficult in many areas and may promote sedimentation to the extent that oysters cannot survive. In areas where oysters are of commercial interest, therefore, eelgrass is considered a pest that must be controlled (Thomas and Duffy 1968).

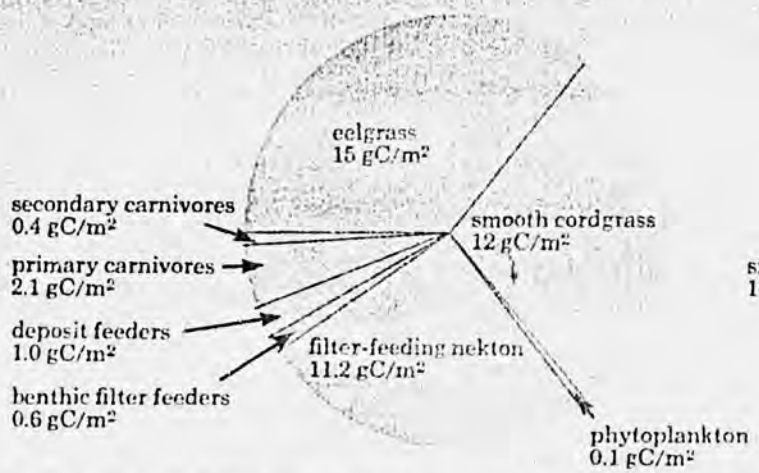
Esthetics are difficult to relate to other human activities or to the value of the seagrass community. Water-oriented recreation, with the exception of recreational fishing, however, is relatively incompatible with seagrass. Swimming beaches are made less attractive by the presence of a high-tide drift row of decaying grass, and water-skiing or swimming is unpleasant over the soft, muddy sedimentary bottoms characteristic of seagrass beds. The notion still prevails that the grass will pull people under. Fishermen, however, are cognizant of the importance of these grass beds for crustaceans, molluscs, and fishes. Numerous investigators have shown that seagrass beds generally have a denser faunal community than adjacent unvegetated bottoms. To those who view "naturalness" as an ideal state, seagrass meadows have a distinct esthetic value—attested to by birdwatchers and photographers—but this appreciation is currently enjoyed by only a small minority.

Consequences of seagrass destruction

The ecological consequences of seagrass destruction have been extensively documented during and since the sudden and drastic decline of eelgrass stocks on both sides of the Atlantic Ocean during the 1930s. Along most areas of the U.S. coast 99–100% of the standing stocks of eelgrass were destroyed in one year (Moffitt and Cottam 1941). This disturbance was characterized as "wasting disease" (Renn 1936), but its direct cause is still subject to question. The decline of fauna dependent upon *Zostera* was widespread, from small epifauna and infauna to fishes and waterfowl (Phillips 1974). These organisms are dependent on *Zostera* for food (detritus and its associated microbes, epiphytes, or epifauna), sediment stabilization, and protection afforded by the grass blades themselves. Perhaps the best documentation is in the literature on the sequence of events near Woods Hole, Mass. (Allee 1923; Dexter 1950). As the eelgrass declined, most of the animal species characteristic of the community disappeared. Many years later, when eelgrass became reestablished in limited areas, the entire community reappeared, but only in those areas where eelgrass was found.

Man's destruction of grass beds has often had similar effects. Flemer et al. (1967) noted a 71% reduction in average number of organisms in a Chesapeake Bay spoil area after dredging ceased. The area was soon repopulated by *Solen viridis* (green razor-shell clams), but thereafter population changes were erratic and total benthic biomass declined. Briggs and O'Connor (1971) noted that the diversity and density of species of fish generally decrease when vegetated areas are covered by dredge spoil. They further pointed out that some species may be entirely eliminated as a result of destruction of natural vegetation that provides both food and cover.

Taylor and Saloman (1968) estimated that the destruction of 1,100 tonnes (metric tons) of seagrass, primarily *Thalassia*, by burial and removal during dredging of Boca Ciega Bay, Fla., resulted in the immediate loss of approximately 1,800 tonnes of infauna. They also estimated that at least 73 tonnes of fishery products and 1,100 tonnes of



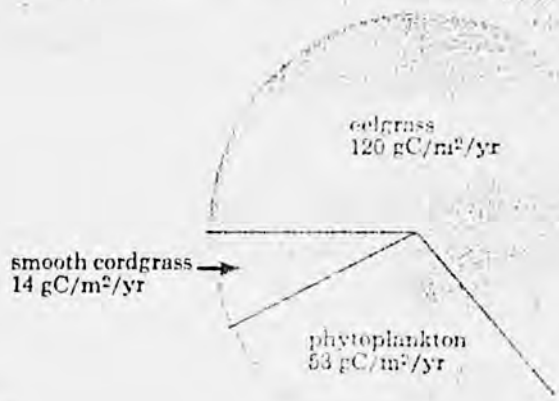


Figure 5. *Left:* Relation among standing crops (in terms of carbon) of organisms in the 400 square kilometer estuarine system near Beaufort, N.C. (Data from R. B. Williams, unpubl.) *Right:* Organic production (in terms of carbon) by the major plants in the estuarine system. (Data from Williams 1973.)

macroinvertebrate infauna were lost annually as a result of the dredging. This estimated loss of fishery production was based on standing crops of fishes collected in Texas grass beds, fish production estimates for Gulf coast estuaries, and the assumption that these values were representative for fishes utilizing grass beds in Boca Ciega Bay; macroinvertebrate production estimates were based on biomass data for the bay and an assumed invertebrate-production-to-biomass ratio of four.

Thus, the basic direct value of seagrass to its community is well established, and the potential value to top carnivores in the estuarine ecosystem can be estimated. These estimates must be put in a broader context, however, to enable proper evaluation of the real benefits of seagrasses to the estuarine ecosystem. We must consider the proportionate role of seagrasses in the energetic scheme of all estuarine and coastal productivity, upon which most of the fishery organisms used by man depend during some stage of their development.

In the area of Beaufort, productivity of eelgrass, phytoplankton, and cordgrass *(Spartina alterniflora)* has been evaluated; preliminary estimates of standing crop on a seasonal basis are available for benthic macroinvertebrates, zooplankton, and fish; and annual commercial yields of fish and shellfish are available (see Fig. 5).

A preliminary synthesis of the trophic structure (R. B. Williams, unpubl.) suggests that a mean ecological efficiency of about 20% is required from the calculated sources of primary production to the annual production of fishery species in the Beaufort estuarine system —that is, an average of 20% of the material consumed at each trophic level is converted to tissue by the consumer organism. Respiration may account for about 75% of the assimilated energy for herbivores and detrital-feeding invertebrates (Teal 1962) and about 90% for fishes (Mann 1965; Adams 1974). Since assimilation may range from 20–60% of consumption for invertebrates (Miller and Mann 1973) and is about 80% for fishes (Mann 1965), most of the primary production is ultimately channeled into organisms used by man. While it is difficult to evaluate the utilization of different sources of primary production separately, the combined sources appear related directly to the fishery output of this estuarine system.

The relative contributions of seagrass would obviously vary between systems and species of seagrass, but the magnitude of Williams's estimate (64% of total productivity) suggests the importance of eelgrass to the total estuarine ecosystem. Synergism further amplifies the role of *Zostera*: loss of the seagrass results in increased turbidity which decreases the productivity not only of remaining *Zostera* but also of phytoplankton and benthic algae. On the other hand, redistribution of bottom sediments may enhance productivity by increasing availability of mineral nutrients. The relative effects of these processes cannot now be quantified, but they should be considered carefully in developing priorities for man's ultimate use of the coastal zone.

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Chapter 7. THE STRUCTURE OF THE NUCLEUS OF THE ATOM

"What?" exclaimed Roger, as Karen rolled over on the bed and rested her warm body against his. "I know some nuclei are spherical and some are ellipsoidal, but where did you find out that some fluctuate in between?"

Karen pursed her lips. "They've been observed with a short-wavelength probe . . ."