



# The Management of Natural Coastal Carbon Sinks

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# Seagrass Meadows

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### Fast facts

- Flowering marine plants that form extensive meadows and are globally distributed. Found in shallow waters of all continents except the Antarctic.
- Responsible for about 15% of total carbon storage in the ocean.
- Global extent of seagrass now estimated to be about 0.3 million km<sup>2</sup>.
- Turnover time of seagrass biomass is long (2 weeks to 5 years for leaves and roots, while rhizomes can sometimes persist for millennia), relative to that of phytoplankton, making the role of seagrasses in the oceanic carbon budget proportionally more significant than expected from their areal cover.
- Long-term carbon burial of 83 g C m<sup>-2</sup>yr<sup>-1</sup>. This translates to global storage rates of between 27 and 40 Tg C yr<sup>-1</sup>.
- The seagrass *Posidonia oceanica* is currently thought to be the most effective species in terms of long-term carbon storage. It is endemic to the Mediterranean and locally widespread. The capacity of its meadows to accumulate carbon exceeds that of many terrestrial ecosystems such as boreal forests and show values commensurate with wetlands.
- However, two-thirds of the world's seagrass meadows within inhabited areas have been lost through human activities that lead to eutrophication and siltation.
- Management plans aimed at reducing the nutrient loads and preserving water clarity of coastal waters are a priority.

Seagrasses, a globally distributed group of marine flowering plants, form extensive meadows that are one of the world's most productive ecosystems. The seagrass leaves degrade slowly and, through their roots and rhizomes, seagrasses deposit large amounts of underground, partly mineralised, carbon. Thus, they constitute an important CO<sub>2</sub> sink, responsible for about 15% of the total carbon storage in the ocean. In this chapter, we present a brief overview of what seagrasses are; their ecological functions and their importance as carbon sinks; the threats to them; as well as recommendations on how to manage them to preserve/restore their capacity.

### 1. Ecosystem definition and global occurrence

The seagrasses, a functional group of about 60 different species of underwater flowering plants, have a near global distribution, and form extensive seagrass meadows in the coastal waters of all the world's continents except the Antarctic (Figure 1). In temperate areas, the meadows are usually dominated by one or a few species (e.g. *Zostera marina* in the North Atlantic), whereas tropical meadows are usually more diverse, often with up to ten or even thirteen species.

**Extent and the functions they provide in the marine ecosystem:** The global extent of seagrass meadows



Figure 1 *Syringodium* sp growing in dense meadows off the coast of Tanga, Tanzania. (photo Jerker Tamelander/IUCN)

has been estimated to between 0.6 million km<sup>2</sup> (Charpy-Roubaud & Sournia, 1990) and 0.3 million km<sup>2</sup> (Green & Short, 2003; Duarte et al., 2005), with the latter estimate taking into account reports of long-term decline rates in seagrass coverage. Although seagrass meadows cover a relatively small portion of the ocean (approx 1%), they play an important role in the coastal zone and provide ecosystem goods and services that have been estimated to be of high value compared with other marine and terrestrial habitats (Costanza et al., 1997). Furthermore, the presence of seagrass meadows is global, unlike mangroves, corals or salt marsh plants, which have a more limited spatial distribution (Short et al., 2007)

Seagrass meadows provide important services supporting the overall functioning of the coastal zone. Some larger animals (like dugongs, turtles, geese, and some fish) are able to digest seagrass leaves. However, more important is the fact that the leaves of seagrasses often become covered by a wide range of algae and invertebrates, which are eaten by a variety of fauna, which both live within the seagrass meadow and migrate from outside the meadows. The dense cover of seagrass shoots also constitutes a sheltering structure, attracting several species of animals. Fish use the seagrass meadow as a nursery where their fry can hide, prawns settle in the seagrass meadows at their post-larval stage and remain there until they become adults (Watson et al. 1993). Moreover, several

animals migrate from other habitats, like coral reefs and mangrove areas, to the seagrass meadows to feed (Unsworth et al. 2008), suggesting that seagrass meadows provide an important link between terrestrial and other marine habitats (Heck et al., 2008).

Other important functions of seagrass meadows are their sediment trapping and sediment binding capacities. They trap suspended materials from the currents, and thereby clear the water. The rhizome and root systems stabilise the sediments and help prevent coastal erosion during storms, rains and floods. Seagrass detritus is also important, through export and maintenance of food-webs in deeper waters and as an important carbon sink, due to its slow rate of decomposition.

**Biomass and production:** The average standing biomass built up within seagrass meadows of 184 gCm<sup>-2</sup> (Duarte & Chiscano, 1999) is relatively low compared with terrestrial ecosystems as it represents less than 1% of the average standing biomass in tropical, temperate and boreal forests combined (Table 1,). In contrast, the absolute rate of seagrass net production (400-817 gC m<sup>-2</sup> yr<sup>-1</sup>), which is of comparable magnitude to other coastal plants, is in fact higher than most terrestrial ecosystems (Table 1, Duarte & Chiscano, 1999; Mateo et al., 2006). Added to this, in the marine environment, the turnover time of seagrass leaves is long (15-1827 days), relative to the few days of phytoplankton,

Ecosystem	NPP (gC m <sup>-2</sup> a <sup>-1</sup> )	Standing stock (gC m <sup>-2</sup> )		Area (*10 <sup>12</sup> m <sup>2</sup> )	NPP (PgC a <sup>-1</sup> )	Global carbon stocks (PgC)	
		Plants	Soil			Plants	Soil
Tropical forests	778	12045	12,273	17.6	13.7	212	216
Temperate forests	625	5673	9,615	10.4	6.5	59	100
Boreal forests	234	6423	34,380	13.7	3.2	88	471
Tropical savannas and grasslands	787	2933	11,733	22.5	17.7	66	264
Temperate grasslands and shrublands	424	720	23,600	12.5	5.3	9	295
Deserts and semi- deserts	31	176	4,198	45.5	1.4	8	191
Tundra	105	632	12,737	9.5	1	6	121
Croplands	425	188	8,000	16	6.8	3	128
Wetlands	1229	4286	72,857	3.5	4.3	15	225
Seagrass meadows ( <i>Posidonia oceanica</i> )	400-817 (60-184 <sup>a</sup> )	184 (124 <sup>b</sup> )	7,000 <sup>c</sup> (40,000- 160,000 <sup>d</sup> )	0.3 (0.035)	0.49 (0.002- 0.0064)	0.06 (0.004)	2.1 (1.4-5.6)

Table 1 Comparison of carbon stocks on a unit area basis in terrestrial ecosystems (Janzen et al., 2004) and seagrass meadows (Duarte & Cebrian 1996, Duarte & Chiscano 1999, Duarte et al., 2005), with global pools determined by using the reported surface areas covered by each ecosystems.

a. Pergent et al., 1994, b. Romero et al., 1992, c. Calculated using organic carbon concentration of 0.7 wt%, porosity of 80% and dry solid density 2.5 g cm<sup>-3</sup>, d. Mateo et al., 1997

making the role of seagrasses in the oceanic carbon budget proportionally more significant than expected from their cover or primary production alone (Smith, 1981).

Many seagrasses also deposit considerable amounts of carbon in their below-ground tissues with ratios of below-ground to above-ground biomass ranging from 0.005 to 8.56 (Duarte & Chiscano, 1999). Larger seagrass species tend to develop high below-ground biomass and hence have a greater capacity for accumulation of carbon due to the relatively slow turnover of the roots and rhizomes (40 days to 19 years). The seagrass species *Posidonia oceanica* can bury large amounts of the carbon it produces, resulting in partly mineralised, several metres thick, underground *mattes* with an organic carbon content of as much as 40 %. These *mattes* can persist for millennia, thus representing a long-term carbon sink (Pergent et al., 1994; Romero et al., 1994; Mateo et al., 1997, 2006).

## 2. Carbon cycling in the ecosystem and its importance as a carbon sink

**Fate of carbon:** The proportion of biomass produced by seagrasses that is directed into carbon storage is dependent on the extent to which carbon is channelled through herbivory, export and decomposition.

Estimates of herbivory, decomposition and export all vary greatly due to the intrinsic properties of individual species and although carbon fluxes in different species may follow the same general routes, the relative importance of the different carbon pathways among seagrass species may differ widely.

Overall, herbivory generally has a limited role in constraining seagrass biomass with most estimates being <10% of plant production. In coastal vegetation, only mangroves have a lower proportion of their net biomass production lost through herbivory (Duarte & Cebrian, 1996; Cebrian, 2002). The extent of herbivory in seagrasses reflects specific intra and inter-species differences and ranges from negligible values up to 50% of net production (Cebrian & Duarte 1998; Mateo et al., 2006). An important fact to note is that few herbivores consume below-ground production and yet these tissues (roots and rhizomes) can constitute 15-50% of the net production. Thus, in some species the below-ground deposits can accumulate and contribute strongly to the carbon stored in the sediment.

Thus, only a small proportion of seagrass biomass is lost to herbivory and the major pathway for leaf production is to enter the detritus, some fraction of which is exported, while most is decomposed locally.

Compared to other coastal plants, the decomposition rate of seagrass tissues is low, averaging  $0.0107 \text{ d}^{-1}$ , compared to  $0.0526 \text{ d}^{-1}$  for phytoplankton and  $0.082 \text{ d}^{-1}$  for mangroves (Enriquez et al., 1993, Duarte & Chiscano, 1999). The difference among ecosystems in the fraction of net production that is decomposed has been suggested to be related to tissue nutrient concentrations, with the slower growing seagrass species generally having lower nutrient concentrations (Duarte, 1990) and hence the lowest decomposition rates. In addition, roots and rhizomes generally tend to have a lower nutrient concentration than leaves, leading to the slower decomposition of below-ground than above-ground biomass.

Based on a compilation of available data, Duarte & Cebrian (1996) estimated that the largest part of the biomass produced is decomposed (50%), with export and herbivory amounting to 24. and 19% respectively, and the remaining 16% is stored (Figure 1). However, it must be noted that these are average values and therefore do not identify the relative importance of different seagrass species, in that some species may route more carbon to storage than others. The data compilation also showed an imbalance in the number of observations that constitute each average value, with observations for seagrass above ground biomass and net production far outweighing the number of observations of below-ground biomass, herbivory, export, decomposition and storage, with the latter probably being the least reported. For example, in a recent assessment of long-term (i.e. decades) carbon burial in vegetated sediments, the measured rates of carbon burial comprised of only five estimates and in

a compilation of short-term (i.e. years) accumulation of seagrass tissues, the data set for carbon storage comprised of only about ten estimates. The accuracy of some estimates can also be called into question as they have not been measured directly, but have been calculated by measuring the other carbon routes and simply assuming that storage represents the missing term in the carbon budget.

**Carbon storage:** Estimates of the short-term (years) carbon storage in sediments average  $133 \text{ gC m}^{-2} \text{ yr}^{-1}$  (range  $10\text{-}350 \text{ gC m}^{-2} \text{ yr}^{-1}$ ,  $n=10$ , Cebrian, 2002). This value compares well with direct estimates of longer term carbon burial, averaging  $83 \text{ gC m}^{-2} \text{ yr}^{-1}$  (range  $45\text{-}190 \text{ gC m}^{-2} \text{ yr}^{-1}$ ,  $n=5$ , Duarte et al., 2005). These values translate to global storage rates of between  $27 \text{ TgC yr}^{-1}$  and  $40 \text{ TgC yr}^{-1}$  assuming the areal coverage of seagrass as  $0.3 \times 10^{12} \text{ m}^2$ . The data sets used in calculations of longer term carbon burial are obtained from a restricted geographical area (the Mediterranean) and are representative of meadows consisting of only two seagrass species (*Cymodocea nodosa* and *Posidonia oceanica*). It is not yet clear whether other seagrass species (e.g. *Thalassodendron ciliatum*, *Posidonia australis* and *P. oceanica*), which are known to produce organic matter that generates refractory deposits, also make a significant contribution to long term carbon burial (Mateo et al., 2006). The estimates of short term carbon storage, although more geographically spread, only include four additional geographic areas (in America and Europe) and two additional types of seagrass (*Zostera sp.* and *Thalassia testudinum*).

Based on the data from Duarte et al (2005), most

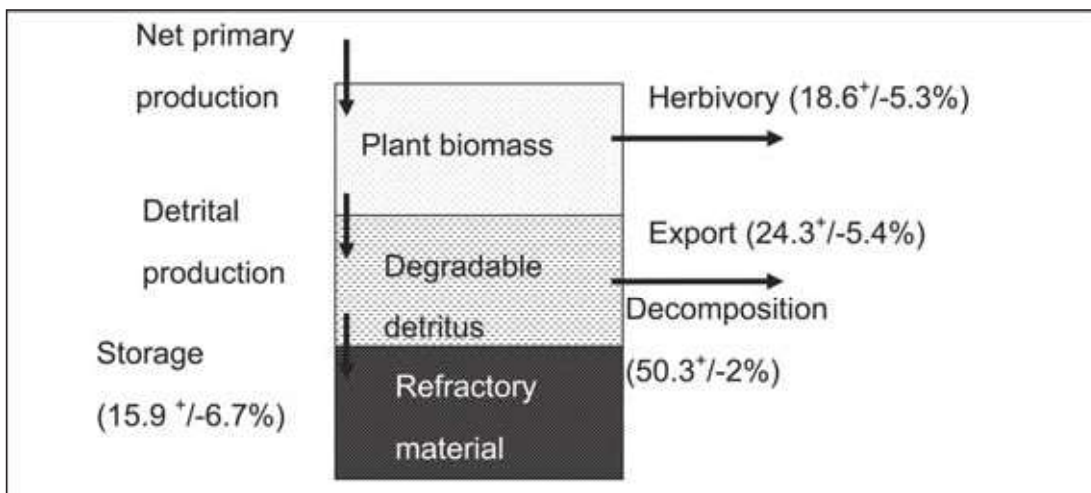


Figure 2 Fate of primary production, values in brackets represent % of net primary production. The data were derived by averaging independent estimates from a range of seagrass species (adapted from Cebrian 1999 & Duarte & Cebrian 1996)

Ecosystem type	Long-term rate of accumulation (gC m <sup>-2</sup> a <sup>-1</sup> )
Tropical forests	2.3-2.5
Temperate forests	1.4 – 12.0
Boreal forests	0.8 – 2.2
Temperate grasslands	2.2
Temperate deserts	0.8
Tundra	0.2 – 5.7
Wetlands	20
<i>Posidonia oceanica</i> meadows	9 – 112

Table 2 Long-term carbon accumulation rates in Holocene (<10,000yr old) soils and wetlands (Schlesinger 1990, Armentano & Menges 1986) and *Posidonia oceanica* (6,000 yr old) as one of the few species of seagrass that accumulate refractory organic matter in below-ground deposits termed mattes (Romero et al., 1994, Mateo et al., 1997, 2006).

seagrass burial rates are about half as high as those for mangroves and salt marshes on an areal basis, and account for 12%, 9% and 25% respectively of the total carbon burial in coastal sediments. However, the rates of long-term carbon accumulation by *Posidonia oceanica* exceed those of terrestrial ecosystems and show values commensurate with wetlands (Table 2). Reported cases of seagrass loss have increased by an order of magnitude over the last 40 years (Orth et al., 2006) and the areal extent of seagrasses has been estimated to have reduced by 50% over a period of about 15 years (Duarte et al 2005), thus it is possible that the proportion of the global carbon sink that is represented by seagrass meadows has been depleted by a similar amount. Hence, a better quantification of the magnitude of carbon sinks in seagrass meadows and a better understanding of future trends for seagrass meadows will be necessary if we are to fully realise how the capacity of the coastal zone to act as a carbon sink will change in the future.

### 3. Threats to the ecosystem

Human interventions have altered coastal habitats severely, causing extensive losses in seagrass habitats (Orth et al., 2006; Björk et al., 2008). For example, in the northwest Atlantic 65% of eelgrass has been lost south of Cape Cod, an industrialized area, as compared to only 20% lost north of Cape Cod, a less populated and industrialized area, since European settlement (Short & Short, 2003). It has even been proposed that two thirds of the seagrass meadows of the world within inhabited areas have been lost (Lotze et al., 2006). The major causes of decline are anthropogenic disturbances that lead to eutrophication and siltation; drivers that

may be accelerated by global climate change now and in the near future. Sedimentation from watershed, terrestrial deforestation and mangrove clearing leads to transport of sediments through rivers and streams to estuaries and coastal waters, reducing water clarity and negatively affecting seagrass growth and development. Similarly, eutrophication caused by waste discharges into coastal areas have major impacts on water clarity, thus reducing the light available to seagrass (Terrados et al., 1998). Seagrasses are particularly susceptible to alterations in water clarity as they normally require higher light levels compared to other aquatic vegetation.

Global change impacts, such as increases in the concentration of CO<sub>2</sub> in seawater and consequently decreasing pH values (ocean acidification), will probably directly affect seagrass photosynthesis and growth. However, as of today, too little data is available to predict the effects of such changes on the productivity of seagrass meadows. The main effect of global change will probably be synergistic, where already stressed seagrass systems will be exposed to additional stressors, further reducing productivity and eventually resulting in increased losses of seagrass meadows (Björk et al., 2008).

### 4. Management recommendations to enhance the potential of the ecosystem as a carbon sink

The carbon sink service that seagrass meadows provide can only be sustained by preserving the health and extent of the world's seagrass meadows. Evidence shows that it is difficult to reverse seagrass loss at the meadow scale (Ralph et al., 2005; Orth et al., 2006), but conservation and restoration of less extensively affected meadows could be possible. Thus, management should be directed towards maintaining general environmental conditions that favour seagrass growth. However, since different seagrass species appear to have different capacities for carbon storage, it is also possible to specifically target those to maximise their carbon storage function.

#### Management aimed at preserving general health of seagrass meadows:

Because the observed global decline in seagrass distribution is mainly caused by human activities such as sediment loading and eutrophication, management plans aimed at reducing the nutrient loads and preserving water clarity of coastal waters becomes a priority (Björk et al., 2008). Controlling anthropogenic activities is one of the main ways that good seagrass health and hence productivity

can be preserved (see Short et al., 2002, Short & Burdick, 2005, Björk et al., 2008). To provide the most favourable conditions a number of requirements must be met. 1. A high water quality, This mean low turbidity waters, low concentrations of coloured dissolved organic matter and low levels of eutrophication. All of these will ensure that the waters support sufficient light penetration for seagrasses to thrive. 2. Good sediment conditions. The sediments should experience only low levels of disturbance/mechanical perturbations, low carbon accumulation rates and low concentrations of sulphide. 3. Maintenance of genetic variability and connectivity with other biological systems, and 4. Favourable water movement

In recent years it has become evident that these requirements cannot be met without creating a public awareness of the purpose of the management plans, and ensuring the participation by stakeholders, both in planning and implementation of management strategies.

**Management aimed at preserving especially high carbon storage capacity:** There are certain features of seagrasses that can enhance their potential to act as important sites for carbon storage. The low nutrient concentrations and high proportion of structural carbon in seagrass tissues, enhance carbon accumulation in the meadow by slowing down the destruction of organic carbon, and the large proportion of below ground biomass enhance carbon accumulation in the meadow by burying organic carbon quickly, before it can be exported from the meadow. It follows that the greatest proportion of organic carbon preserved in the sediments will be found in meadows consisting of slow growing species with a high allocation of biomass to the growth of below ground organs.

Of all the seagrasses studied, *Posidonia oceanica* probably represents one of the best species for carbon storage; it is also the best studied species in terms of carbon burial and probably provides the best estimate of the size of the carbon sink in at least one area of our coastal oceans. *Posidonia oceanica* is widespread and endemic to the Mediterranean and sustains carbon burial rates of 17-191 g Cm<sup>-2</sup> yr<sup>-1</sup>, forming a *matte* that can be thousands of years old. The thickness of the *matte* in one bay of the NW Mediterranean has been recently estimated using high-resolution seismo-acoustic imaging (Iacono et al., 2008), allowing the carbon accumulation to be calculated at 0.18 Mg m<sup>-2</sup>. Given that *Posidonia oceanica* is thought to cover

0.035 million km<sup>2</sup> of the Mediterranean, the sediments below *Posidonia oceanica* meadows could represent a store of ~6 x 10<sup>15</sup> tonnes of carbon, with a carbon accumulation rate of between 0.6-7 MgC yr<sup>-1</sup> or 2-24% of global seagrass burial.

Although *Posidonia oceanica* may appear to make the Mediterranean a hot spot in terms of carbon burial, other seagrass species may, although today undiscovered, have similar potential for carbon burial. Even species with a lower carbon burial but a more widespread distribution may actually make a larger overall contribution to global carbon storage. Thus to make accurate predictions concerning the fate of seagrass production on a global scale, reliable estimates of the distribution and density of the dominating seagrass species in all different biogeographical regions and the potential of each species for carbon burial would be needed. These figures for seagrasses are not currently available as shown in a review of the literature on seagrass ecology (Duarte 1999). Of the papers reviewed in this study, 25% related to the ecology of just two of the seagrass species (*Thalassia testudinum* + *Posidonia oceanica*) and there was a geographic bias in published results, with 50% of the studies being undertaken in Caribbean and Mediterranean seagrass meadows.

Thus today, although we can only approximate the current importance of seagrass meadows as a carbon sink, the recent focus within the scientific community on global change and the importance of natural carbon sinks has resulted in a large number of research projects aiming at making it possible to incorporate the biogeography of seagrass species and their propensity for carbon storage into an accurate global carbon budget.

### References

- Armentano TV & Menges ES 1986 Patterns of change in the carbon balance of organic soil-wetlands of the temperate zone. *Journal of Ecology* 74, 755-774.
- Björk M., Short F., Mcleod, E. and Beer, S. 2008. Managing seagrasses for resilience to climate change. IUCN, Gland, Switzerland. 56pp.
- Cebrián J. (2002) Variability and control of carbon consumption, export, and accumulation in marine communities. *Limnol. Oceanogr.* 47(1): 11-22.
- Cebrián J and Duarte CM. (1998) Patterns in leaf herbivory on seagrasses. *Aquatic Botany* 60: 67-82
- Charpy-Roubaud C and Sournia A 1990 The comparative estimation of phytoplankton microphytobenthic production in the oceans. *Marine Microbial Food Webs* 4: 31-57.

- Costanza R, d'Arge R, Groot de R. Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Sutton P, Belt van den M. (1997) The value of the world's ecosystem services and natural capital. *Nature* 387: 253-260.
- Duarte CM. 1990 Seagrass nutrient content. *Marine Ecology Progress Series* 67, 201-207.
- Duarte CM. 1999 Seagrass ecology at the turn of the millennium: challenges for the new century. *Aquatic Botany* 65: 7-20.
- Duarte CM and Cebrián J. 1996 The fate of marine autotrophic production. *Limnol. Oceanogr.* 41(8): 1758-1766.
- Duarte CM and Chiscano CL. 1999 Seagrass biomass and production: a reassessment. *Aquatic Botany* 65: 159-174.
- Duarte CM, Middelburg JJ, Caraco N. 2005 Major role of marine vegetation on the oceanic carbon cycle. *Biogeosciences* 2: 1-8.
- Enriquez S, Duarte CM, Sand-Jensen K. 1993 Patterns in decomposition rates among photosynthetic organisms: the importance of detritus C:N:P content. *Oecologia* 94: 457-471
- Green EP and Short FT 2003 *World Atlas of Seagrasses*. California University Press 310pp
- Heck Jr. KL, Carruthers TJB, Duarte CM, Hughes AR, Kendrick G, Orth RJ Williams SW. 2008 Trophic Transfers from Seagrass Meadows Subsidize Diverse Marine and Terrestrial Consumers. *Ecosystems* 11: 1198-1210.
- Janzen H.H. 2004 Carbon cycling in earth systems – a soil science perspective. *Agriculture ecosystems and Environment* 104, 399-417.
- Lotze, H.K., Lenihan, H.S., Bourque, B.J., Bradbury, R.H., Cooke, R.G., Kay, M.C., Kidwell, S.M. Kirby, M.X., Peterson, C.H. and Jackson, J.B.C. 2006. Depletion, degradation, and recovery potential of estuaries and coastal seas. *Science* 312: 1806-1809.
- Mateo MA, Romero J, Pérez, Littler MM, Littler DS. 1997 Dynamics of Millenary Organic Deposits Resulting from the Growth of the Mediterranean Seagrass *Posidonia oceanica*. *Estuarine, Coastal and Shelf Science* 44: 103-110.
- Mateo MA Cebrian J Dunton K Mutchler T 2006 Carbon flux in seagrass ecosystems. In W.D. Larkum, R.J. Orth, C.M. Duarte (Eds). *Seagrasses: Biology, Ecology and Conservation*. Springer 567-593.
- Orth RJ, Carruthers TJB, Dennison WC, Duarte CM, Fourqurean JW, Heck Jr. KL, Hughes AR, Kendrick GA, Kenworthy WJ, Olyarnik S, Short FT, Waycott M, Williams SL. 2006 A Global Crisis for Seagrass Ecosystems. *Bioscience* 56: (12) 987-996.
- Pergent G. Romero J. Pergent-Martini C. Mateo M-A. Boudouresque C-F 1994 Primary production, stocks and fluxes in the Mediterranean seagrass *Posidonia oceanica*. *Marine Ecology Progress Series* 106, 139-146.
- Ralph PJ Tomasko D Moore K Seddon S Macinnis-Ng CAO 2006 Human impacts on seagrasses: Eutrophication, sedimentation and contamination. In W.D. Larkum, R.J. Orth, C.M. Duarte (Eds). *Seagrasses: Biology, Ecology and Conservation*. Springer 567-593.
- Romero J. Pergent G. Pergent-Martini C. Mateo M-A. Regnier C. 1992 The detritic compartment in a *Posidonia oceanica* meadow: litter features, decomposition rates, and mineral stocks. *PSZNI Marine Ecology* 13(1) 69-83.
- Romero J, Pérez M, Mateo MA, Sala A. 1994 The belowground organs of the Mediterranean seagrass *Posidonia oceanica* as a biogeochemical sink. *Aquatic Botany* 47: 13-19
- Schlesinger WH 1990 Evidence from chronosequence studies for a low carbon storage potential of soils. *Nature* 348, 232-234.
- Short FT and Short CA 2003. Seagrass distribution in the western North Atlantic. in: *World Atlas of Seagrasses*, Green EP, Short TF (eds) *World Atlas of Seagrasses*. University of California Press, Berkeley.
- Short FT and Burdick DM 2005 "Eelgrass Restoration and Site Selection Model" A CD that utilises readily available local data to determine prioritized locations for the restoration of eelgrass beds. When coupled with a GIS program, maps are produced that identify sites with the best potential for eelgrass restoration. For a copy, email: seagrass.net@unh.edu
- Short, F.T., Davis, R.C., Kopp, B.S., Short, C.A., and Burdick, D.M. 2002 Site selection model for optimal restoration of eelgrass, *Zostera marina* L. *Marine Ecology Progress Series* 227: 263-267.
- Short F, Carruthers T, Dennison W, Waycott M. (2007) Global seagrass distribution and diversity: A bioregional model. *Journal of Experimental Marine Biology and Ecology* 350: 3-20.
- Smith SV. (1981) Marine Macrophytes as a Global Carbon Sink. *Science* 211: 838-840.
- Terrados, J., Duarte, C.M., Fortes, M.D., Borum, J., Agawin, N.S.R., Bach, S., Thampanya, U., Kamp-Nielsen, L., Kenworthy, W.J., Geertz-Hansen, O. Vermaat, J. 1998. Changes in community structure and biomass of seagrass communities along gradients of siltation in SE Asia. *Estuarine, Coastal and Shelf Science* 46: 757-768.
- Unsworth, R.K.F., De León, P.S., Garrard, S.L., Jompa, J., Smith, D.J. and Bell, J.J. 2008. High connectivity of Indo-Pacific seagrass fish assemblages with mangrove and coral reef habitats. *Marine Ecology Progress Series* 353: 213-224.
- Watson, R.A., Coles, R.G. and Lee Long, W.J. 1993. Simulation estimates of annual yield and landed values for commercial penaeid prawns from tropical seagrass habitat, Northern Queensland, Australia. *Australian Journal of Marine and Freshwater Research* 44: 211-219.