February 2008

Marine Science Review - 248

Habitats and ecosystems

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In this review:

O/A denotes an open access article or journal

A. Recent articles with abstracts

Schlacher, T.A., Dugan, J., Schoeman, D.S., Lastra, M., Jones, A., Scapini, F., McLachlan, A., and Defeo, O. **Sandy beaches at the brink.** *Diversity and Distributions* 13(5): 556-560, 2007.

Notes: Sandy beaches line most of the world's oceans and are highly valued by society: more people use sandy beaches than any other type of shore. While the economic and social values of beaches are generally regarded as paramount, sandy shores also have special ecological features and contain a distinctive biodiversity that is generally not recognized. These unique ecosystems are facing escalating anthropogenic pressures, chiefly from rapacious coastal development, direct human uses - mainly associated with recreation - and rising sea levels. Beaches are increasingly becoming trapped in a 'coastal squeeze' between burgeoning human populations from the land and the effects of global climate change from the sea. Society's interventions (e.g. shoreline armouring, beach nourishment) to combat changes in beach environments, such as erosion and shoreline retreat, can result in severe ecological impacts and loss of biodiversity at local scales, but are predicted also to have cumulative large-scale consequences worldwide. Because of the scale of this problem, the continued existence of beaches as functional ecosystems is likely to depend on direct conservation efforts. Conservation, in turn, will have to increasingly draw on a consolidated body of ecological theory for these ecosystems. Although this body of theory has yet to be fully developed, we identify here a number of critical research directions that are required to progress coastal management and conservation of sandy beach ecosystems.

McKee, K.L., Cahoon, D.R., and Feller, I.C. **Caribbean mangroves adjust to rising sea level through biotic controls on change in soil elevation.** *Global Ecology and Biogeography* 16(5): 545-556, 2007.

Notes: *Aim* The long-term stability of coastal ecosystems such as mangroves and salt marshes depends upon the maintenance of soil elevations within the intertidal habitat as sea level changes. We examined the rates and processes of peat formation by mangroves of the Caribbean Region to better understand biological controls on habitat stability. *Location* Mangrove-dominated islands on the Caribbean coasts of Belize, Honduras and Panama were selected as study sites. *Methods* Biological processes controlling mangrove peat formation were manipulated (in Belize) by the addition of nutrients (nitrogen or phosphorus) to *Rhizophora mangle* (red mangrove), and the effects on the dynamics of soil elevation were determined over a 3-year period using rod surface elevation tables (RSET) and marker horizons. Peat composition and geological accretion rates were determined at all sites using radiocarbon-dated cores. *Results* The addition of nutrients to mangroves caused significant changes in rates of mangrove root accumulation, which influenced both the rate and direction of change in elevation. Areas with low root input lost elevation and those with high rates gained elevation. These findings were consistent with peat analyses at multiple Caribbean sites showing that deposits (up to 10 m in depth) were composed primarily of mangrove root matter. Comparison of radiocarbon-dated cores at the study sites with a sea-level curve for the western Atlantic indicated a tight coupling between peat building in Caribbean mangroves and sea-level rise over the Holocene. *Main conclusions* Mangroves common to the Caribbean region have adjusted to changing sea level mainly through subsurface accumulation of refractory mangrove roots. Without root and other organic inputs, submergence of these tidal forests is inevitable due to peat decomposition, physical compaction and eustatic sea-level rise. These findings have relevance for predicting the effects of sea-level rise and biophysical processes on tropical mangrove ecosystems.

Airoldi, L. and Beck, M.W. **Loss, status and trends for coastal marine habitats of Europe.** *Oceanography and Marine Biology: An Annual Review* 45: 345-405, 2007.

Notes: Over the centuries, land reclamation, coastal development, overfishing and pollution have nearly eliminated European wetlands, seagrass meadows, shellfish beds, biogenic reefs and other productive and diverse coastal habitats. It is estimated that every day between 1960 and 1995, a kilometre of European coastline was developed. Most countries have estimated losses of coastal wetlands and seagrasses exceeding 50% of the original area with peaks above 80% for many regions. Conspicuous declines, sometimes to virtual local disappearance of kelps and other complex macroalgae, have been observed in several countries. A few dominant threats have led to these losses over time. The greatest impacts to wetlands have consistently been land claim and coastal development. The greatest impacts to seagrasses and macroalgae are presently associated with degraded water quality while in the past there have been more effects from destructive fishing and diseases. Coastal development remains an important threat to seagrasses. For biogenic habitats, such as oyster reefs and maerls, some of the greatest impacts have been from destructive fishing and overexploitation with additional impacts of disease, particularly to native oysters. Coastal development and defence have had the greatest known impacts on soft-sediment habitats with a high likelihood that trawling has affected vast areas. The concept of 'shifting baselines', which has been applied mostly to the inadequate historical perspective of fishery losses, is extremely relevant for habitat loss more generally. Most habitat loss estimates refer to a relatively short time span primarily within the last century. However, in some regions, most estuarine and near-shore coastal habitats were already severely degraded or driven to virtual extinction well before 1900. Native oyster reefs were ecologically extinct by the 1950s along most European coastlines and in many bays well before that. These shellfish reefs are among the most endangered coastal habitats, but they receive some of the least protection. Nowadays less than 15% of the European coastline is considered in 'good' condition. Those fragments of native habitats that remain are under continued threat, and their management is not generally informed by adequate knowledge of their distribution and status. There are many policies and directives aimed at reducing and reversing these losses but their overall positive benefits have been low. Further neglecting this long history of habitat loss and transformation may ultimately compromise the successful management and future sustainability of those few fragments of native and semi-native coastal habitats that remain in Europe.

Spalding, M.D., Fox, H.E., Halpern, B.S., McManus, M.A., Molnar, J., Allen, G.R., Davidson, N., Jorge, Z.A., Lombana, A.L., Lourie, S.A., Martin, K.D., McManus, E., Molnar, J., Recchia, C.A., and Robertson, J. **Marine ecoregions of the world: A bioregionalization of coastal and shelf areas.** *BioScience* 57(7): 573-583, 2007. **O/A**

Notes: The conservation and sustainable use of marine resources is a highlighted goal on a growing number of national and international policy agendas. Unfortunately, efforts to assess progress, as well as to strategically plan and prioritize new marine conservation measures, have been hampered by the lack of a detailed, comprehensive biogeographic system to classify the oceans. Here we report on a new global system for coastal and shelf areas: the Marine Ecoregions of the World, or MEOW, a nested system of 12 realms, 62 provinces, and 232 ecoregions. This system provides considerably better spatial resolution than earlier global systems, yet it preserves many common elements and can be cross-referenced to many regional biogeographic classifications. The designation of terrestrial ecoregions has revolutionized priority setting and planning for terrestrial conservation; we anticipate similar benefits from the use of a coherent and credible marine system.

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de Boer, W.F. **Seagrass-sediment interactions, positive feedbacks and critical thresholds for occurrence: a review.** *Hydrobiologia* 591: 5-24, 2007.

Notes: This literature review summarizes the limiting factors for seagrass occurrence, and the effect positive feedbacks in seagrass systems have on these threshold levels. Minimum water depth is mainly determined by wave orbital velocity, tide and wave energy; and maximum depth by light availability. Besides these, other limiting factors occur, such as an upper current velocity threshold, above which seagrasses are eroded, or a lower water current velocity threshold below which carbon exchange is limiting. In some locations organic matter content, sulphide concentration or nutrient availability are limiting. N-limitation is mainly reported from temperate terrigenous sediments, and P-limitation from tropical carbonate sediments.

However, limiting factors sometimes change over the year, switching from light limiting to N- or P-limiting, and show at times regional variation. The effect seagrasses have on current reduction, trapping sediment and decreasing resuspension can lead to several changes in both the sediment and the water column. In the sediment, an increase in nutrient availability has been reported, and increases in organic matter, sediment height increases, and burial of the seagrasses. In the water column the effect is a reduction of the turbidity through a decrease of the sediment load, decreasing the attenuation coefficient, thereby increasing light availability. Due to the large effect light availability has on seagrass occurrence, the effect of an improvement of the light conditions by a reduction of the turbidity by seagrasses is probably the most important positive feedback in seagrass systems. The latter effect should therefore be incorporated in models that try to understand or predict seagrass changes. Generalization are difficult due a lack of studies that try to find relationships between seagrass architecture and sediment trapping (studying both turbidity reduction and nutrient increase) on a global level under a variety of different conditions. Areas for research priorities are identified

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Davies, A.J., Roberts, J.M., and Hall-Spencer, J. **Preserving deep-sea natural heritage: Emerging issues in offshore conservation and management.** *Biological Conservation* 138(3-4): 299-312, 2007.

Notes: Human activity in the deep sea is extending ever deeper, with recent research showing that this environment is more sensitive to human and natural impacts than previously thought. Some deep-water fish stocks have collapsed and fishing methods such as bottom trawling have raised international concern over the habitat damage they cause. It is likely that in its current form, deep-sea fishing is unsustainable. Diminishing reserves of hydrocarbons in shallow water are pushing exploration and production into deeper waters, which may cause damage to little known deep-sea habitats. The deep sea is also proposed as an environment where anthropogenic carbon dioxide could be stored to minimise the effect of its release into the atmosphere. At the same time, rising atmospheric carbon dioxide levels may be altering the chemical equilibrium of the global ocean by lowering pH. Many countries are now beginning to designate some deep-sea habitats as marine protected areas in measures to reduce the damage caused by fishing and other anthropogenic activities. This review examines these current and emerging issues in deep-sea conservation and discusses conservation status and the designation of protected areas. The enforcement of protected areas using satellite tracking of vessels is discussed and applied to an internationally agreed deep-water conservation area, which aims to protect cold-water coral habitats on the Darwin Mounds in the north east Atlantic Ocean.

Stachowicz, J.J., Bruno, J.F., and Duffy, J.E. **Understanding the effects of marine biodiversity on communities and ecosystems.** *Annual Review of Ecology, Evolution, and Systematics* 38: 739-766, 2007.

Notes: There is growing interest in the effects of changing marine biodiversity on a variety of community properties and ecosystem processes such as nutrient use and cycling, productivity, stability, or trophic transfer.We review published marine experiments that manipulated the number of species, genotypes, or functional groups. This research reveals several emerging generalities. In studies of primary producers and sessile animals, diversity often has a weak effect on production or biomass, especially relative to the strong effect exerted by individual species. However, sessile taxon richness did consistently decrease variability in community properties, and increased resistance to, or recovery from disturbance or invasion. Multitrophic-level studies indicate that, relative to depauperate assemblages of prey species, diverse ones (*a*) are more resistant to top-down control, (*b*) use their own resources more completely, and (*c*) increase consumer fitness. In contrast, predator diversity can either increase or decrease the strength of top-down control because of omnivory and because interactions among predators can have positive and negative effects on herbivores. Recognizing that marine and terrestrial approaches to understanding diversity-function relationships are converging, we close with suggestions for future research that apply across habitats.

Huber, J.A., Welch, D.B.M., Morrison, H.G., Huse, S.M., Neal, P.R., Butterfield, D.A., and Sogin, M.L. **Microbial population structures in the deep marine biosphere.** *Science* 318(5847): 97-100, 2007.

Notes: The analytical power of environmental DNA sequences for modeling microbial ecosystems depends on accurate assessments of population structure, including diversity (richness) and relative abundance (evenness). We investigated both aspects of population structure for microbial communities at two neighboring hydrothermal vents by examining the sequences of more than 900,000 microbial small-subunit ribosomal RNA amplicons. The two vent communities have different population structures that reflect local geochemical regimes. Descriptions of archaeal diversity were nearly exhaustive, but despite collecting an unparalleled number of sequences, statistical analyses indicated additional bacterial diversity at every taxonomic level. We predict that hundreds of thousands of sequences will be necessary to capture the vast diversity of microbial communities, and that different patterns of evenness for both high- and low-abundance taxa may be important in defining microbial ecosystem dynamics.

Bowen, J.L., Kroeger, K.D., Tomasky, G., Pabich, W.J., Cole, M.L., Carmichael, R.H., and Valiela, I. **A review of land–sea coupling by groundwater discharge of nitrogen to New England estuaries: Mechanisms and effects.** *Applied Geochemistry* 22(1): 175-191, 2007.

Notes: Hydrologists have long been concerned with the interface of groundwater flow into estuaries, but not until the end of the last century did other disciplines realize the major role played by groundwater transport of nutrients to estuaries. Mass balance and stable isotopic data suggest that land-derived NO_3, NH_4, and dissolved organic N do enter estuaries in amounts likely to affect the function of the receiving ecosystem. Because of increasing human occupancy of the coastal zone, the nutrient loads borne by groundwater have increased in recent decades, in spite of substantial interception of nutrients within the land and aquifer components of watersheds. Groundwater-borne nutrient loads have increased the N content of receiving estuaries, increased phytoplankton and macroalgal production and biomass, decreased the area of seagrasses, and created a cascade of associated ecological changes. This linkage between land use and eutrophication of estuaries occurs in spite of mechanisms, including uptake of land-derived N by riparian vegetation and fringing wetlands, "unloading" by rapid water removal, and direct N inputs to estuaries, that tend to uncouple the effects of land use on receiving estuaries. It can be expected that as human activity on coastal watersheds continues to increase, the role of groundwater-borne nutrients to the receiving estuary will also increase.

Deegan, L.A., Bowen, J.L., Drake, D., Fleeger, J.W., Friedrichs, C.T., Galvan, K.A., Hobble, J.E., Hopkinson, C., Johnson, D.S., Johnson, J.M., Lemay, L.E., Miller, E., Peterson, B.J., Picard, C., Sheldon, S., Sutherland, M., Vallino, J., and Warren, R.S. **Susceptibility of salt marshes to nutrient enrichment and predator removal.** *Ecological Applications* 17(5): S42-S63, 2007.

Notes: Salt marsh ecosystems have been considered not susceptible to nitrogen overloading because early studies suggested that salt marshes adsorbed excess nutrients in plant growth. However, the possible effect of nutrient loading on species composition, and the combined effects of nutrients and altered species composition on structure and function, was largely ignored. Failure to understand interactions between nutrient loading and species composition may lead to severe underestimates of the impacts of stresses. We altered whole salt marsh ecosystems (~ 60 000 m^2/treatment) by addition of nutrients in flooding waters and by reduction of a key predatory fish, the mummichog. We added nutrients (N and P; 15-fold increase over ambient conditions) directly to the flooding tide to mimic the way anthropogenic nutrients are delivered to marsh ecosystems. Despite the high concentrations (70 mmol N/L) achieved in the water column, our annual N loadings (15-60 g $N \cdot m^{-2} \cdot yr^{-1}$) were an order of magnitude less than most plot-level fertilization experiments, yet we detected responses at several trophic levels. Preliminary calculations suggest that 30-40% of the added N was removed by the marsh during each tidal cycle. Creek bank *Spartina alterniflora* and high marsh *S. patens* production increased, but not stunted high marsh *S. alterniflora*. Microbial production increased in the fertilized creek bank *S. alterniflora* habitat where benthic microalgae also increased. We found top-down control of benthic microalgae by killifish, but only under nutrient addition and in the opposite direction (increase) than that predicted by a fish-invertebrate-microalgae trophic cascade. Surprisingly, infauna declined in abundance during the first season of fertilization and with fish removal. Our results demonstrate ecological effects of both nutrient addition and mummichog reduction at the whole-system level, including evidence for synergistic interactions.

Elliott, M., Burdon, D., Hemingway, K.L., and Apitz, S.E. **Estuarine, coastal and marine ecosystem restoration: Confusing management and science - A revision of concepts.** *Estuarine, Coastal and Shelf Science* 74(3): 349-366, 2007.

Notes: This review presents recent concepts, understanding and experience of the restoration, recovery and human-mediated modification of estuarine, coastal and marine ecosystems. It shows that these can be divided into four categories: natural recovery from a natural or anthropogenic change (whether adverse or otherwise); anthropogenic interventions in response to a degraded or anthropogenically changed environment; anthropogenic responses to a single stressor; and habitat enhancement or creation. A conceptual framework for restoration and recovery of marine marginal and semi-enclosed areas is presented after exploring and refining the plethora of terms used in restoration science and management. Examples of management action are given including managed realignment and the restoration of docks, biogenic reefs, saltmarsh, seagrass, beaches and upper estuarine water quality. We emphasise that although recovery techniques are worthwhile if they can be carried out, they rarely (if ever) fully replace lost habitat. Moreover, while they may have some success in marginal or semi-enclosed areas such as coastal bays, estuaries and fringing habitats, they are less relevant to open coastal and marine habitats. Therefore the best option available in the latter can only be to remove the stressor, as the cause of any change, to prevent other stressors from operating and to allow the conditions suitable for natural recovery. This review emphasises that whereas some ecological concepts related to restoration are well understood, for example, the nature of ecosystem structure and functioning, others such as carrying capacity, resilience and ecosystem goods and services are still poorly quantified for the marine and estuarine environments. The linking between these ecological concepts and the management framework is also relatively recent but is required to give a holistic approach to understanding, managing and manipulating these environments.

Al Yamani, F.Y., Bishop, J.M., Al Rifaie, K., and Ismail, W. **The effects of the river diversion, Mesopotamian Marsh drainage and restoration, and river damming on the marine environment of the northwestern Arabian Gulf.** *Aquatic Ecosystem Health and Management* 10(3): 277-289, 2007.

Notes: This paper summarizes the results of a study, which was conducted during the period of 1996-2005. It assesses the impact of river diversion (Third River), marsh drainage, and marsh restoration on Kuwait's marine environment. The results indicated lower salinity, higher nitrate concentration, higher chlorophyll *a*, and higher sedimentation in the northern waters of Kuwait influenced by the discharge of the man-made Third River and marsh drainage. Five estuarine copepod species, which occur only in the northern waters of Kuwait due to their proximity to the mouth of the river, are reported here for the first time. Lower turbidity levels were observed in the northern waters of Kuwait during 2004 and 2005 possibly influenced by the marsh restoration process. The above results indicate the close interrelationship between the upstream river environment and the northern Arabian Gulf. River-related activities in the Tigris-Euphrates Basin have transboundary impacts downstream. Assumptions on the potential effects of the upstream damming of the Tigris and Euphrates Rivers on Kuwait's marine environment are included. It is expected that recent and planned river basin modifications in Turkey, Iran and Iraq will significantly reduce river discharge, permanently remove seasonal flooding, and impact the northern Gulf's marine environment, with serious implications for fisheries.

Halpern, B.S., Selkoe, K.A., Micheli, F., and Kappel, C.V. **Evaluating and ranking the vulnerability of global marine ecosystems to anthropogenic threats.** *Conservation Biology* 21(5): 1301-1315, 2007.

Notes: Marine ecosystems are threatened by a suite of anthropogenic stressors. Mitigating multiple threats is a daunting task, particularly when funding constraints limit the number of threats that can be addressed. Threats are typically assessed and prioritized via expert opinion workshops that often leave no record of the rationale for decisions, making it difficult to update recommendations with new information. We devised a transparent, repeatable, and modifiable method for collecting expert opinion that describes and documents how threats affect marine ecosystems. Experts were asked to assess the functional impact, scale, and frequency of a threat to an ecosystem; the resistance and recovery time of an ecosystem to a threat; and the certainty of these estimates. To quantify impacts of 38 distinct anthropogenic threats on 23 marine ecosystems, we surveyed 135 experts from 19 different countries. Survey results showed that all ecosystems are threatened by at least nine threats and that nine ecosystems are threatened by >90% of existing threats. The greatest threats (highest impact scores) were increasing sea temperature, demersal destructive fishing, and point-source organic pollution. Rocky reef, coral reef, hard-shelf, mangrove, and offshore epipelagic ecosystems were identified as the most threatened. These general results, however, may be partly influenced by the specific expertise and geography of respondents, and should be interpreted with caution. This approach to threat analysis can identify the greatest threats (globally or locally), most widespread threats, most (or least) sensitive ecosystems, most (or least) threatened ecosystems, and other metrics of conservation value. Additionally, it can be easily modified, updated as new data become available, and scaled to local or regional settings, which would facilitate informed and transparent conservation priority setting.

Heymans, J.J., Guenette, S., and Christensen, V. **Evaluating network analysis indicators of ecosystem status in the Gulf of Alaska.** *Ecosystems* 10(3): 488-502, 2007.

Notes: This is the first study on the emergent properties for empirical ecosystem models that have been validated by time series information. Ecosystem models of the western and central Aleutian Islands and Southeast Alaska were used to examine indices of ecosystem status generated from network analysis and incorporated into Ecopath with Ecosim. Dynamic simulations of the two ecosystems over the past 40 years were employed to examine if these indices reflect the dissimilar changes that occurred in the ecosystems. The results showed that the total systems throughput (TST) and ascendancy (A) followed the climate change signature (Pacific decadal oscillation, PDO) in both ecosystems, whereas the redundancy (R) followed the inverse trend. The different trajectories for important species such as Steller sea lions (*Eumetopias jubatus*), Atka mackerel (*Pleurogrammus monopterygius*), pollock (*Theragra chalcograma*), herring (*Clupea pallasii*), Pacific cod (*Gadus macrocephalus*) and halibut (*Hippoglossus stenolepis*) were noticeable in the Finn cycling index (FCI), entropy (H) and average mutual information (AMI): not showing large change during the time that the Stellers sea lions, herring, Pacific cod, halibut and arrowtooth flounder (*Atheresthes stomias*) increased in Southeast Alaska, but showing large declines during the decline of Steller sea lions, sharks, Atka mackerel and arrowtooth flounder in the Aleutians. On the whole, there was a change in the emergent properties of the Aleutians around 1976 that was not seen in Southeast Alaska. Conversely, the emergent properties of both systems showed a change around 1988, which indicated that both systems were unstable after 1988.

Tewfik, A., Rasmussen, J.B., and McCann, K.S. **Simplification of seagrass food webs across a gradient of nutrient enrichment.** *Canadian Journal of Fisheries and Aquatic Sciences* 64(7): 956-967, 2007.

Notes: Anthropogenic nutrient enrichment has resulted in significant changes in food web structure. Although such changes have been associated with the loss of diversity and ecosystem services, little empirical work has been done to study food webs of similar systems across a nutrient enrichment gradient. We examined 11 seagrass beds along a gradient of increasing $\delta^{15}N$ of primary consumers, where $\delta^{15}N$ is used as an indicator of sewage-derived nutrients. Observations across this gradient revealed corresponding increases in consumer density and changes in distinct functional groups, whereas consumer diversity, seagrass canopy, and macrodetrital biomass decreased. However, maximum overall primary consumer diversity and minimum density occurred at intermediate levels along the nutrient gradient. We hypothesize that higher species diversity at low to moderate levels of nutrient enrichment depends on the persistence of grazer-resistant seagrass. This seagrass canopy, and the significant macrodetritus it generates, facilitates a variety of food and shelter resources. Overgrazed and simplified habitats may occur when densities of generalist urchins, capable of direct producer consumption, are no longer controlled through competition, predation, and intraguild predation. We hypothesize that high and stable urchin populations appear possible with the increased availability of allochthonous phytoplankton and associated particulate detritus that is a well-known consequence of nutrient enrichment in aquatic systems.

Blaber, S.J.M. **Mangroves and fishes: Issues of diversity, dependence, and dogma.** *Bulletin of Marine Science* 80(3): 457-472, 2007.

Notes: Tropical estuarine fishes are inextricably linked with mangroves, which are the dominant vegetation of tropical and subtropical estuaries. Among the most productive of aquatic areas and heavily exploited, their future may depend upon ecosystem understanding. This paper reviews diversity, dependence, and connectivity between mangroves and fisheries in the light of data from previously unstudied systems in developing countries and new approaches in developed countries. Fish diversity in mangroves varies at global, latitudinal, regional, local and habitat scales, and species composition in any one system represents the combined influences of factors operating at each of these scales. Mangrove dependence paradigms require critical evaluation as new data become available and as catches and mangrove areas decline. Although it is a widely held dogma that mangroves are essential for fish populations, most evidence is circumstantial. Therefore experimental and quantitative studies are needed to support arguments that the value of retaining mangroves exceeds that of their destruction.

Koenig, C.C., Coleman, F.C., Eklund, A.M., Schull, J., and Ueland, J. **Mangroves as essential nursery habitat for goliath grouper (*Epinephelus itajara*).** *Bulletin of Marine Science* 80(3): 567-585, 2007.

Notes: We evaluated goliath grouper's [*Epinephelus itajara* (Lichtenstein, 1822)] use of mangroves as essential nursery habitat by estimating absolute abundance, density, survival, age structure, home range, mangrove habitat association, habitat quality, and recruitment to the adult population. Densities (numbers km^{-1} mangrove shoreline) were calculated using Jolly-Seber mark-recapture methods for mangrove-lined rivers and mangrove islands of the Ten Thousand Islands (TTI) and Everglades National Park, which includes Florida Bay, Florida, USA. Juveniles had smaller home ranges around islands (170 m) than in rivers (586 m), as determined from observations on telemetered fish. Goliath grouper remained in mangrove habitats for 5-6 yrs (validated ages from dorsal spine sections), then emigrated from mangroves at about 1.0 m total length. In the TTI, juvenile densities around mangrove islands were higher (mean = 25 km^{-1}, SE = 6.2, CV = 0.5) and less variable than those in rivers (mean = 11 km^{-1}, SE = 4.2, CV = 1.2). Density was negatively correlated with the frequency of dissolved oxygen and salinity minima. Mean growth rate of recaptured fish around mangrove islands (0.358 mm d^{-1}, 95% CL = 0.317-0.398) was significantly higher than that in rivers (0.289 mm d^{-1}, 95% CL = 0.269-0.308). The annual survival rate, as estimated by the Kaplan-Meier method on telemetered fish, was 0.947 (95% CL = 0.834-1.0). Very low densities in Florida Bay were probably related to other water-quality variables in this human-altered system. The offshore abundance of adults was largely explained by abundance of mangrove, but not seagrass habitat. Mangrove habitat with suitable water conditions, which appears essential to the recovery and sustainability of goliath grouper populations, should be protected and/or restored.

Coen, L.D., Brumbaugh, R.D., Bushek, D., Grizzle, R., Luckenbach, M.W., Posey, M.H., Powers, S.P., and Tolley, S.G. **Ecosystem services related to oyster restoration.** *Marine Ecology Progress Series* 341: 303-307, 2007.

Notes: The importance of restoring filter-feeders, such as the Eastern oyster *Crassostrea virginica*, to mitigate the effects of eutrophication (e.g. in Chesapeake Bay) is currently under debate. The argument that bivalve molluscs alone cannot control phytoplankton blooms and reduce hypoxia oversimplifies a more complex issue, namely that ecosystem engineering species make manifold contributions to ecosystem services. Although further discussion and research leading to a more complete understanding is required, oysters and other molluscs (e.g. mussels) in estuarine ecosystems provide services far beyond the mere top-down control of phytoplankton blooms, such as (1) seston filtration, (2) benthic-pelagic coupling, (3) creation of refugia from predation, (4) creation of feeding habitat for juveniles and adults of mobile species, and for sessile stages of species that attach to molluscan shells, and (5) provision of nesting habitat.

Granek, E.F. and Ruttenberg, B.I. **Protective capacity of mangroves during tropical storms: a case study from 'Wilma' and 'Gamma' in Belize.** *Marine Ecology Progress Series* 343: 101-105, 2007.

Notes: Globally threatened mangrove forest habitat is often considered an important buffer protecting coastlines from wave and storm impacts and coastal erosion. However, there is little empirical data quantifying the protective effects of mangroves during storms, primarily because of the difficulty of predicting where and when a storm will intersect the shoreline, to facilitate data collection before and after storm events. In 2005, opportunistic results from an ongoing study quantifying differences between intact and cleared mangrove areas on Turneffe Atoll, Belize, provided such pre- and post-storm data from tropical storms 'Wilma' (later a Category 5 Hurricane) and 'Gamma'. We compared differences in equipment retention rates of 3 types of experimental devices previously installed in adjacent intact and cleared mangrove areas. Retention rates were greater in intact mangrove areas, empirically demonstrating the protective capacity of mangroves during moderate magnitude storm events. The results support the assumption that removal of mangroves diminishes coastal protection not only during catastrophic storm events such as hurricanes or tsunamis, but also during less energetic but more frequent events, such as tropical storms. This highlights the importance of improved coastal zone management, as storm events may increase in frequency and intensity with changing climate, and coastal mangrove forest habitats continue to decline in size and number.

Palacios, S.L. and Zimmerman, R.C. **Response of eelgrass *Zostera marina* to CO_2 enrichment: possible impacts of climate change and potential for remediation of coastal habitats.** *Marine Ecology Progress Series* 344: 1-13, 2007.

Notes: Projected increases in dissolved aqueous concentrations of carbon dioxide [CO_2(aq)] may have significant impacts on photosynthesis of CO_2-limited organisms such as seagrasses. Short-term CO_2(aq) enrichment increases photosynthetic rates and reduces light requirements for growth and survival of individual eelgrass *Zostera marina* L. shoots growing in the laboratory under artificial light regimes for at least 45 d. This study examined the effects of long-term CO_2(aq) enrichment on the performance of eelgrass growing under natural light-replete (33% surface irradiance) and light-limited (5% surface irradiance) conditions for a period of 1 yr. Eelgrass shoots were grown at 4 CO_2(aq) concentrations in outdoor flow-through seawater aquaria bubbled with industrial flue gas containing approximately 11% CO_2. Enrichment with CO_2(aq) did not alter biomass-specific growth rates, leaf size, or leaf sugar content of above-ground shoots in either light treatment. CO_2(aq) enrichment, however, led to significantly higher reproductive output, below-ground biomass and vegetative proliferation of new shoots in light-replete treatments. This suggests that increasing the CO_2 content of the atmosphere and ocean surface will increase the area-specific productivity of seagrass meadows. CO_2(aq) enrichment did not affect the performance of shoots grown under light limitation, suggesting that the transition from carbon- to light-limited growth followed Liebig's Law. This study also demonstrated that direct injection of industrial flue gas could significantly increase eelgrass productivity; this might prove useful for restoration efforts in degraded environments. The broader effects of CO_2(aq) enrichment on the function of natural seagrass meadows, however, require further study before deliberate CO_2 injection could be considered as an engineering solution to the problem of seagrass habitat degradation.

Hammerstrom, K.K., Kenworthy, W.J., Whitfield, P.E., and Merell, M.F. **Response and recovery dynamics of seagrasses *Thalassia testudinum* and *Syringodium filiforme* and macroalgae in experimental motor vessel disturbances.** *Marine Ecology Progress Series* 345: 83-92, 2007.

Notes: Shallow seagrass beds worldwide are being negatively impacted by human activities. Damage by boats includes anchor scars, propeller scars, and hull groundings. In some *Thalassia testudinum*-dominated systems, vessel damage may persist for years or decades, and even small scars may leave seagrass habitat susceptible to severe erosion by wind and wave-driven currents and storms. Cost-effective techniques for restoration in these erosion-prone systems must include sediment replacement and stabilization to best enhance seagrass recovery. We conducted 2 experiments to address the effects of excavation depth and sediment filling on seagrass and macroalgal recovery into small-scale disturbances such as propeller scars. Recovery in excavations ≥ 20 cm deep took 2 to 5 yr longer than recovery in shallower disturbances (10 cm). Seagrasses were able to grow in native limestone fill material (diameter 0.6 cm), although the compensatory response of *Syringodium filiforme* was dampened.

Short, F., Carruthers, T., Dennison, W., and Waycott, M. **Global seagrass distribution and diversity: A bioregional model.** *Journal of Experimental Marine Biology and Ecology* 350(1-2): 3-20, 2007.

Notes: Seagrasses, marine flowering plants, are widely distributed along temperate and tropical coastlines of the world. Seagrasses have key ecological roles in coastal ecosystems and can form extensive meadows supporting high biodiversity. The global species diversity of seagrasses is low (<60 species), but species can have ranges that extend for thousands of kilometers of coastline. Seagrass bioregions are defined here, based on species assemblages, species distributional ranges, and tropical and temperate influences. Six global bioregions are presented: four temperate and two tropical. The temperate bioregions include the Temperate North Atlantic, the Temperate North Pacific, the Mediterranean, and the Temperate Southern Oceans. The Temperate North Atlantic has low seagrass diversity, the major species being *Zostera marina*, typically occurring in estuaries and lagoons. The Temperate North Pacific has high seagrass diversity with *Zostera* spp. in estuaries and lagoons as well as *Phyllospadix* spp. in the surf zone. The Mediterranean region has clear water with vast meadows of moderate diversity of both temperate and tropical seagrasses, dominated by deep-growing *Posidonia oceanica*. The Temperate Southern Oceans bioregion includes the temperate southern coastlines of Australia, Africa and South America. Extensive meadows of low-to-high diversity temperate seagrasses are found in this bioregion, dominated by various species of *Posidonia* and *Zostera*. The tropical bioregions are the Tropical Atlantic and the Tropical Indo-Pacific, both supporting mega-herbivore grazers, including sea turtles and sirenia. The Tropical Atlantic bioregion has clear water with a high diversity of seagrasses on reefs and shallow banks, dominated by *Thalassia testudinum*. The vast Tropical Indo-Pacific has the highest seagrass diversity in the world, with as many as 14 species growing together on reef flats although seagrasses also occur in very deep waters. The global distribution of seagrass genera is remarkably consistent north and south of the equator; the northern and southern hemispheres share ten seagrass genera and only have one unique genus each. Some genera are much more speciose than others, with the genus *Halophila* having the most seagrass species. There are roughly the same number of temperate and tropical seagrass genera as well as species. The most widely distributed seagrass is *Ruppia maritima*, which occurs in tropical and temperate zones in a wide variety of habitats. Seagrass bioregions at the scale of ocean basins are identified based on species distributions which are supported by genetic patterns of diversity. Seagrass bioregions provide a useful framework for interpreting ecological, physiological and genetic results collected in specific locations or from particular species.

Koch, M.S., Schopmeyer, S.A., Nielsen, O.I., Kyhn-Hansen, C., and Madden, C.J. **Conceptual model of seagrass die-off in Florida Bay: Links to biogeochemical processes.** *Journal of Experimental Marine Biology and Ecology* 350(1-2): 73-88, 2007.

Notes: Seagrasses are recognized as important plant communities in coastal estuaries and lagoons across both tropical and temperate climes; thus, large-scale seagrass die-off events worldwide are of general concern. In Florida Bay, at the southern terminus of the Florida peninsula, seagrass die-off events up to 4000 ha have been reported and smaller scale mortality events are noted annually. In the present study, we examined several hypothesized causative factors (high temperature, hypersalinity, sulfide toxicity) of seagrass (*Thalassia testudinum*) mortality in Florida Bay. To test sulfide effects, in situ sulfide production was stimulated by applying a labile carbon source (glucose) to sulfate reducers in the sediment at five sites across the bay (northeastern, northcentral, and southwestern basins). During the one year study, high temperature (32-36ºC) and salinity (>50 psu) were recorded in the bay associated with a regional drought. We also experienced major seagrass die-off events at two of our southwestern bay sites. These field conditions provided an excellent opportunity to closely examine cause-effect relationships among stressors and die-off events in the field, and verify results of our previous mesocosm experiments. Even though glucose amendments stimulated porewater sulfides in bay sediments (4-8 mmol L^{-1}), no significant differences in biomass, short shoot density or final growth rates were found between control and glucose plots. In addition, the highest growth rates and shoot densities were concomitant with maximum water column salinity (>50 psu) and temperature (32-36ºC), when porewater sulfides were also in the millimolar range. Large-scale seagrass mortality events, encompassing ~ 50% of the entire meadow at one site, occurred at southwestern bay sites when plants were down regulating (slower growth and shoot density), probably in response to shorter day length and lower temperature (30-34 to 23-26ºC) from October, 2004 to January, 2005. Sulfate reduction rates (SRR) were also 2-fold higher in the southwestern (214-488 nmol cm^{-3} d^{-1}) versus northcentral and northeastern (97-240 nmol cm^{-3} d^{-1}) bay sites, possibly limited by labile carbon, which we found to stimulate SRR 3-fold in northeastern and northcentral bay sites (461-708 nmol cm^{-3} d^{-1}) and 4-fold at southwestern bay sites (1211-2036 nmol cm^{-3} d^{-1}). Based on a synthesis of the field data reported herein, our mesocosm experiments to date, and contributions by others, we present a conceptual model of seagrass die-off in Florida Bay outlining a cascade of stressors, stimulated by P enrichment, which leads to high 0_2 consumption in the system triggering a seagrass die-off event.

Burkholder, J.M., Tomasko, D.A., and Touchette, B.W. **Seagrasses and eutrophication.** *Journal of Experimental Marine Biology and Ecology* 350(1-2): 46-72, 2007.

Notes: This review summarizes the historic, correlative field evidence and experimental research that implicate cultural eutrophication as a major cause of seagrass disappearance. We summarize the underlying physiological responses of seagrass species, the potential utility of various parameters as indicators of nutrient enrichment in seagrasses, the relatively sparse available information about environmental conditions that exacerbate eutrophication effects, and the better known array of indirect stressors imposed by nutrient over-enrichment that influence seagrass growth and survival. Seagrass recovery following nutrient reductions is examined, as well as the status of modeling efforts to predict seagrass response to changing nutrient regimes. The most common mechanism invoked or demonstrated for seagrass decline under nutrient over-enrichment is light reduction through stimulation of high-biomass algal overgrowth as epiphytes and macroalgae in shallow coastal areas, and as phytoplankton in deeper coastal waters. Direct physiological responses such as ammonium toxicity and water-column nitrate inhibition through internal carbon limitation may also contribute. Seagrass decline under nutrient enrichment appears to involve indirect and feedback mechanisms, and is manifested as sudden shifts in seagrass abundance rather than continuous, gradual changes in parallel with rates of increased nutrient additions. Depending on the species, interactions of high salinity, high temperature, and low light have been shown to exacerbate the adverse effects of nutrient over-enrichment. An array of indirect effects of nutrient enrichment can accelerate seagrass disappearance, including sediment re-suspension from seagrass loss, increased system respiration and resulting oxygen stress, depressed advective water exchange from thick macroalgal growth, biogeochemical alterations such as sediment anoxia with increased hydrogen sulfide concentrations, and internal nutrient loading via enhanced nutrient fluxes from sediments to the overlying water. Indirect effects on trophic structure can also be critically important, for example, the loss of herbivores, through increased hypoxia/anoxia and other habitat shifts, that would have acted as "ecological engineers" in promoting seagrass survival by controlling algal overgrowth; and shifts favoring exotic grazers that out-compete seagrasses for space. Evidence suggests that natural seagrass population shifts are disrupted, slowed or indefinitely blocked by cultural eutrophication, and there are relatively few known examples of seagrass meadow recovery following nutrient reductions. Reliable biomarkers as early indicators of nutrient over-enriched seagrass meadows would benefit coastal resource managers in improving protective measures. Seagrasses can be considered as "long-term" integrators (days to weeks) of nutrient availability, especially through analyses of their tissue content, and of activities of enzymes such as nitrate reductase and alkaline phosphatase. The ratio of leaf nitrogen content to leaf mass has also shown promise as a "nutrient pollution indicator" for the seagrass *Zostera marina*, with potential application to other species. In modeling efforts, seagrass response to nutrient loading has proven difficult to quantify beyond localized areas because long-term data consistent in quality are generally lacking, and high inter-annual variability in abundance and productivity depending upon stochastic meteorological and hydrographic conditions. Efforts to protect remaining seagrass meadows from damage and loss under eutrophication, within countries and across regions, are generally lacking or weak and ineffective. Research needs to further understand about seagrasses and eutrophication should emphasize experimental studies to assess the response of a wider range of species to chronic, low-level as well as acute, pulsed nutrient enrichment. These experiments should be conducted in the field or in large-scale mesocosms following appropriate acclimation, and should emphasize factor interactions (N, P, C; turbidity; temperature; herbivory) to more closely simulate reality in seagrass ecosystems. They should scale up to address processes that occur over larger scales, including food-web dynamics that involve highly mobile predators and herbivores. Without any further research, however, one point is presently very clear: Concerted local and national actions, thus far mostly lacking, are needed worldwide to protect remaining seagrass meadows from accelerating cultural eutrophication in rapidly urbanizing coastal zones.

Lee, K.S., Park, S.R., and Kim, Y.K. **Effects of irradiance, temperature, and nutrients on growth dynamics of seagrasses: A review.** *Journal of Experimental Marine Biology and Ecology* 350(1-2): 144-175, 2007.

Notes: Productivity of seagrasses can be controlled by physiological processes, as well as various biotic and abiotic factors that influence plant metabolism. Light, temperature, and inorganic nutrients affect biochemical processes of organisms, and are considered as major factors controlling seagrass growth. Minimum light requirements for seagrass growth vary among species due to unique physiological and morphological adaptations of each species, and within species due to photo-acclimation to local light regimes. Seagrasses can enhance light harvesting efficiencies through photo-acclimation during low light conditions, and thus plants growing near their depth limit may have higher photosynthetic efficiencies. Annual temperatures, which are highly predictable in aquatic systems, play an important role in controlling site specific seasonal seagrass growth. Furthermore, both thermal adaptation and thermal tolerance contribute greatly to seagrass global distributions. The optimal growth temperature for temperate species range between 11.5ºC and 26ºC, whereas the optimal growth temperature for tropical/subtropical species is between 23ºC and 32ºC. However, productivity in persistent seagrasses is likely controlled by nutrient availability, including both water column and sediment nutrients. It has been demonstrated that seagrasses can assimilate nutrients through both leaf and root tissues, often with equal uptake contributions from water column and sediment nutrients. Seagrasses use HCOT inefficiently as a carbon source, thus photosynthesis is not always saturated with respect to DIC at natural seawater concentrations leading to carbon limitation for seagrass growth. Our understanding of growth dynamics in seagrasses, as it relates to main environmental factors such as light, temperature, and nutrient availability, is critical for effective conservation and management of seagrass habitats.

Ralph, P.J., Durako, M.J., Enriquez, S., Collier, C.J., and Doblin, M.A. **Impact of light limitation on seagrasses.** *Journal of Experimental Marine Biology and Ecology* 350(1-2): 176-193, 2007.

Notes: Seagrass distribution is controlled by light availability, especially at the deepest edge of the meadow. Light attenuation due to both natural and anthropogenically-driven processes leads to reduced photosynthesis. Adaptation allows seagrasses to exist under these sub-optimal conditions. Understanding the minimum quantum requirements for growth (MQR) is revealed when light conditions are insufficient to maintain a positive carbon balance, leading to a decline in seagrass growth and distribution. Respiratory demands of photosynthetic and non-photosynthetic tissues strongly influence the carbon balance, as do resource allocations between above- and below-ground biomass. Seagrass light acclimation occurs on varying temporal scales, as well as across spatial scales, from the position along a single leaf blade to within the canopy and finally across the meadow. Leaf absorptance is regulated by factors such as pigment content, morphology and physical properties. Chlorophyll content and morphological characteristics of leaves such as leaf thickness change at the deepest edge. We present a series of conceptual models describing the factors driving the light climate and seagrass responses under current and future conditions, with special attention on the deepest edge of the meadow.

Balata, D., Piazzi, L., and Cinelli, F. **Increase of sedimentation in a subtidal system: Effects on the structure and diversity of macroalgal assemblages.** *Journal of Experimental Marine Biology and Ecology* 351(1-2): 73-82, 2007.

Notes: In marine habitats sedimentation is one of the major factors influencing the structure, biomass and metabolism of benthic assemblages. Rates of sedimentation have been increasing over the past few decades in many marine areas, representing a potential threat to marine biodiversity. This study was aimed at assessing the potential impact of sedimentation on the structure of macroalgal assemblages of a rocky reef at about 30 m depth. We tested the hypothesis that an experimental addition of sediments would determine an increase in cover of ephemeral species and a reduction of the total number of species. Results indicated that the experimental increase of sedimentation caused benthic assemblages to become more similar to those observed in areas where loads of sediments are naturally greater. Such a disturbance determined a reduction in alpha diversity and a dominance of filamentous species in a system where the vegetal component is predominant. These findings are in agreement with previous descriptive and experimental studies. However, our study indicated that only a few filamentous forms benefited from increased sedimentation, likely due to their life-history traits. In general, our results suggested that sedimentation could determine severe effects not only on the composition and relative abundance of macroalgal assemblages but also on the alternation of different life-history stages of organisms.
