Non-linearity in ecosystem services: temporal and spatial variability in coastal protection.

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Abstract

Non-linearity in the response of ecological variables (e.g., population growth) to environmental change is well recognized, but the associated change in ecosystem functions and services is typically assumed to be linear. This review illustrates the importance of non-linearity in ecosystem functions to the valuation of ecosystem services and management of coastal systems. We focus on wave attenuation, the main ecosystem function responsible for the service of coastal protection, generated in marshes, mangroves, seagrasses, and coral reefs. We show that wave attenuation is not only nonlinear over both space and time but that the pattern (e.g., points of inflexion, asymptotes) of these functional relationships varies among community types. We suggest that dynamic modeling of ecological functions, greater field-based testing of the functional relationships between ecological condition and ecosystem services, and the economic valuation of those services will increase our accuracy in valuing coastal ecosystems and, in turn, refine ecosystem-based management practices.

In a nutshell
- In the valuation of ecosystem services, ecosystem functions are usually assumed to vary linearly over space and time but ecosystem functions (e.g., wave attenuation) are highly nonlinear. As a result, the generation of the ecosystem services associated with these functions (e.g., coastal protection) is likely to be nonlinear as well.
- Given our findings that non-linearities characterize wave attenuation in coastal ecosystems, it is likely that non-linearity is also common in other important ecosystem services such as provision of fishes and habitats, nutrient uptake, regulation of atmospheric gases, and preservation of biodiversity.
- It is essential that non-linearities in wave attenuation that emerge from factors such as different species traits, timing of storms, and the cumulative effects of other stresses to the system be taken into account when restoring coastal biotic structures for the purpose of enhancing coastal protection.

- Failure to integrate non-linearity in ecosystem services will lead to greater error from over or underestimation of services generated, and potentially to overlooking fundamental, non-linear thresholds at which services turn on and off over space and time.

Introduction

Coastal ecosystems and the services they provide are under global siege. Climate change, nutrient loading, habitat degradation, food-web alteration, and pollution all threaten their persistence (Silliman et al. 2005, Orth et al. 2006, Halpern et al. 2008). Key to conserving these benefit-generating ecosystems is quantifying economic values of services provided and incorporating those values into socio-economic analyses (NRC 2005, Hein et al. 2006). Currently, with few exceptions (e.g. Farnsworth 1998, Gaston 2000, Petersen et al. 2003, Dobson et al. 2006, Aburto-Oropeza et al. 2008), a major underlying assumption of the valuation process is that the quantity of an ecosystem function varies linearly with independent characteristics and forcing variables (e.g., ecosystem size, seasonality, disturbance and species interactions; Barbier et al. 2008a). However, the responses these independent variables generate in ecosystem functions are highly dynamic and non-linear, across both space and time (Farnsworth 1998). For example, the function of wave attenuation by some seagrasses may be at its maximum during summer when plants are reproductive (Chen et al. 2007), at medium levels in spring and fall and non-existent during winter when density and biomass is low. Furthermore, many ecological functions are likely to be characterized by thresholds and asymptotic relationships, as is the case with ecological processes such as population growth, predator functional responses, and species-area relationships (Cain et al. 2008). However, such non-linear relationships between ecological traits and ecosystem function, and ecosystem function and service delivery have not been explored in an in-depth, quantitative or conceptual manner (except see Aburto-Oropeza et al. 2008).

Improvements in the understanding and quantification of non-linearities in ecosystem functions are likely to not only provide more realistic ecosystem service values but also improve ecosystem based management (EBM) practices (Barbier et al. 2008a). Current conservation decision-making practices most often take into account

only the qualitative benefits of ecosystems (e.g., whether or not a habitat is a fish nursery and not the value of the fisheries it maintains) as quantitative measures are generally unavailable. Barbier et al. (2008a) showed the consequences of trading off multiple ecosystem services with and without accounting for non-linear functional responses to habitat size in mangrove systems. We build on this work and examine spatial and temporal heterogeneity in the ecosystem function of wave attenuation across a suite of coastal vegetated habitats (Figure 1). We then quantitatively evaluate how this heterogeneity leads to the non-linear generation of storm protection services. We conclude by discussing the implications of non-linearity in ecosystem functions for management and conservation.

How coastal habitats attenuate waves

Wave attenuation is a function of the amount of plant and sedentary animal material obstructing the water column (Coops et al. 1996) and the bathymetry of the area. Leaves, stems and, in some cases, even roots of coastal vegetation are a source of friction to moving water (Massel et al. 1999), as is the reticulated structure of coral reefs (Madin and Connolly 2006). As a result, the biotic structures in coastal habitats remove momentum from the water, leading to a reduction in current velocity and attenuation of wave energy (Koch et al. 2006). Although this ecosystem function results in coastal protection, it cannot be assumed that the presence of coastal biotic structures leads to the provision of this ecosystem service to its fullest extent (Feagin 2008, Barbier et al. 2008b). For example, a sparse bed of the seagrass *Ruppia maritima* (e.g., early in the growing season) has been shown to contribute little to wave attenuation. The density of the bed needs to reach a threshold of 1,000 shoots m^{-2} before this ecosystem function is provided (Chen et al. 2007).

Coastal biotic structures also contribute to wave attenuation via sediment trapping. As currents and waves are attenuated by the plants, sediment particles can be deposited (Gacia et al. 1999, van Proosdij et al. 2006). As a result, vegetated areas can become shallower over time (Boer 2007), further contributing to wave attenuation. For example, the edges of marshes tend to form levees as coarser particles reaching the marsh

settle out when currents and waves are reduced (Mitsch and Gosselink 1993). This marsh levee also contributes to wave attenuation.

Coastal protection varies over space

Non-linearity in the provision of coastal protection via wave attenuation can be observed from the smallest (meters) to the largest (global) spatial scales. For example, the edge of biotic structures receives the brunt of wave energy and, as a result, provides the highest wave attenuation (Figure 2A) and the most value in terms of coastal protection. However, a narrow marginal fringe may not suffice to reduce wave energy to a non-damaging level for coastal villages, especially during storm events. Shuto (1987) suggested a mangrove belt of 20 or 100 m wide to protect against tsunami waves of 3 and 6 m height, respectively. Likewise, Mazda et al. (1997) predicted that mangrove (*Kandelia candel*) forests as wide as 1,000 m may be required to reduce wave energy by 90%, but due to tree density rather than spatial extent of trees (Massel et al. 1999; Figure 2B). In very dense mangrove forests, full attenuation of wind-induced waves may occur within 30 m of the edge while in low density forests, such as those usually found at the edge of mangrove forests (Komiyama et al. 2008), much wider vegetated areas are required to obtain the same results (Massel et al. 1999).

Coastal protection also likely varies with latitude due to large differences in plant biomass and thus wave attenuation. For example, mangrove above-ground biomass decreases from low to mid latitudes (0 to 40°; Twilley et al. 1992, Komiyama et al. 2008), such that the highest wave attenuation is provided near the equator. For seagrasses, the opposite pattern seems to exist (Figure 2C). Above ground biomass in the summer is lowest in the tropics (0 to 10°), increases at mid-latitudes (20 to 30°), decreases again at 40 to 50° and is maximum at the highest latitude (60°; Duarte and Chiscano 1999). As a result, the ecosystem function of wave attenuation by seagrasses is expected to vary non-linearly over latitudinal scales. Taken together, when considering wave attenuation processes over a broad range of spatial scales, there is a wide range of nonlinearity in the generation of this ecosystem function.

Coastal protection varies over time

Non-linearity in the provision of coastal protection via wave attenuation can also be observed from the smallest (hours) to the largest (decadal) temporal scales. Dissipation of wave energy is a direct function of the percentage of the water column occupied by vegetation (Fonseca and Cahalan 1992). As a result, wave attenuation will depend on tidal level and height of biotic structures. For example, wave attenuation is highest for seagrasses when water levels are low and their biomass is compressed into a smaller water column (Figure 2D). Wave attenuation in seagrasses, marshes and mangroves decreases non-linearly as the tide rises (non-linearly; Figure 2D) but, when water reaches the leaves and branches in mangrove forests, wave attenuation increases again as there are more "obstructions" to wave propagation (Figure 2D; Mazda et al. 2006, Quartel et al. 2007). Overall, coastal protection should be highest when the tide is low and biomass of biotic structures is at its maximum. As such, the value of coastal protection is expected to change seasonally (Coops et al. 1996), especially in temperate areas (Figure 2E) where vegetation can vary dramatically. Similarly, inter-annual variability in plant cover (Figure 2E and F) will affect the magnitude and value of coastal protection.

Coastal protection is also dependent on the timing of natural processes such as storms, hurricanes, and tsunamis. For example, coastal protection will be diminished if storms occur when plant biomass and/or density is low (Figure 3A). This is of particular importance in temperate areas where seasonal fluctuations of biomass may be offset from the seasonal occurrence of storms. For example, biomass of the seagrass *Zostera marina* in Korea peaks in the summer (April – June) yet decreases in the fall (July – September; Kaldy and Lee 2007) when the strongest winds, and thus waves, occur (Figure 3A). In tropical areas, biomass of biotic structures tends to be less variable over time, thus providing more predictable coastal protection throughout the year. For example, mangrove forests, which have a relatively constant biomass throughout the year (Tam et al. 1995), provide a relatively constant ecosystem service independent of typhoon season (Figure 3B).

Coastal protection as a function of species and habitat quality

There is a paucity of studies that compare wave attenuation functions of different species (Bouma et al. 2005). Using aboveground biomass as a proxy for wave attenuation, it seems reasonable to assume that different species have different effects on wave attenuation. The work that has been done shows that highest wave attenuation of subtidal species occurs in communities that occupy the entire water column (Koch et al. 2006). Morphology and biomass distribution of biotic structures also have a major effect on wave attenuation (Massel et al. 1997). For example, wave attenuation by the mangrove *Sonneratia* sp. that has large pneumatophores (roots protruding from the ground into the water/air) exceeds that of *Kandelia candel* that has no aerial roots (Mazda et al. 1997, 2006).

Habitat quality may also influence wave attenuation and add an additional level of complexity to valuation of coastal protection. It makes sense that stressed organisms should have lower biomass and density, which would lead to lower wave attenuation (e.g., Massel et al. 1999). These stresses may be natural (e.g., the degree of flooding in marshes and mangroves contributes to plant size and zonation) but others are certainly anthropogenic (e.g., eutrophication leading to the thinning or loss of seagrasses). Reef crest habitat degraded by bleaching, species turnover, waves and bioerosion is smoother than intact habitat and provides less friction to dampen incoming waves (Sheppard et al. 2005). Healthy mangrove communities characterized by true mangrove genera such as *Rhizophora* and *Sonneratia* suffered little typhoon-related damage in contrast to cryptically degraded mangrove sites dominated by vegetative associates (Dahdouh-Guebas et al. 2005). Additionally, sparse beds of the seagrass *Ruppia maritima* are not effective in attenuating waves. A minimum shoot density of 1,000 m^{-1} is needed in order to attenuate waves (Chen et al. 2007). The influence of habitat quality is an important but understudied aspect of nonlinearity when evaluating the actual value of ecosystem services such as wave attenuation.

Cumulative effects of wave attenuation in coastal systems

As discussed previously, coastal protection is a result of more than the sum of the wave attenuation provided by individual biotic structures; it is the cumulative effect

imposed by biotic and abiotic characteristics of the coastal zone on waves (Feagin 2008, Barbier et al. 2008b). Although biotic structures appear to dampen most of the wave energy, local geomorphology and bathymetry also play a major role via wave shoaling, refraction, reflection, and diffraction processes (Komar 1998). The different species found at various depths provide additional complexity (Quartel et al. 2007), as each biotic community has a different drag coefficient contributing to the wave attenuation.

Waves approaching a coastal area are first affected when they contact the sediment (Figure 4). This may be due to shoaling/shallowing of the area or a reef. The wave then propagates through seagrass beds (often several different species colonizing different depths) where it may be attenuated depending on the fraction of the water column occupied by the vegetation (Fonseca and Cahalan 1992, Koch et al. 2006). An even less energetic wave then reaches the mangroves or marshes where stiffer (woody) species are often 3 times more effective in attenuating waves (Bouma et al., 2005).

Temporal fluctuations in water level (i.e., tides and storm surges) add another level of complexity to wave attenuation (Figure 4). At low tide, when mangroves and marshes are fully exposed to air, only the available seagrasses contribute to wave attenuation (Koch and Gust 1999, Madsen et al. 2001). As waves move shoreward out of the seagrass beds, shoaling may regenerate wave height (negative wave attenuation due to wave build up) until waves reach the shore where they break (i.e., 100% attenuation).

Valuation of non-linear ecosystem services

The recent interest in valuing ecosystem services to more fully understand best management practices necessitates incorporation of the non-linear properties of these services over space and time to more accurately represent their value. Here we expand on a paper by Barbier et al. (2008a) that considers the non-linear properties of ecosystem services in mangroves by incorporating the effect of both plant species and tidal level on the wave attenuation. We calculated the value of storm protection services of *Sonneratia* sp. and *Kandelia candel* mangrove plantations in Vietnam (Mazda et al. 1997) using the methodology of Barbier et al. (2008a) which assumed that each km^2 of mangroves deforested involved the equivalent loss of 100 m mangroves inshore along a 10 km coastline. Wave attenuation by the mangroves is based on data from the coast of Vietnam

(Mazda et al. 1997 and 2006; Wolanski 2007) where *Kandelia candel* and *Sonneratia* sp. mangrove plantations have been created over a wide intertidal shoal as a coastal defense against typhoon waves. The *K. candel* plantation at the study site is 1.5 km wide (perpendicular to the coast) and 3 km long (parallel to the coast). Wave data was measured *in situ* at three locations: at the offshore edge of the forest (no attenuation by the vegetation), 100 m inside the forest, and approximately 1000m from the first sampling site. Observations were collected for each species at two tide levels, mid and high tides. In this system, wave attenuation, and thus the storm protection value, of *Sonneratia* sp. exceeds that of *K. candel*, and both are non-linear (Figure 5A).

The above wave attenuation relationship for each species was then used to adjust the net present value (10% discount rate, 1996$) per km^2 estimate for storm protection following the method described in Barbier et al. (2008a). That is, it is assumed that mangrove deforestation occurs along a 10 km coastline (e.g. 1 km^2 = 100 m x 10,000 m), and we adjust the estimate employed for calculating the value of storm protection per km^2 accordingly. We plot the corresponding non-linear value for storm protection by species in Figure 5B. The difference between the two species in terms of storm protection value is at its maximum when mangrove area reaches 3 km^2 ($11,972,379 and $7,149,601 for *Sonneratia* sp. and *K. candel*, respectively). As mangrove area increases beyond 3 km^2, the storm protection value of both species starts to converge (Figure 5B). At the maximum mangrove area of 10 km^2 the storm protection value is $15,940,572 for *Sonneratia* sp. and $14,317,997 for *K. candel*.

If we consider the effect of tidal height, wave attenuation of *Sonneratia* sp. is greater at mid-tide as opposed to high tide (Figure 5C) and thus the storm protection value of this species is greater at this water level as well (Figure 5D; $11,972,379 and $6,098,261 for mid and high tide, respectively, at 3 km^2). However, because of the non-linearity in this relationship, the difference declines as the mangrove area increases. At the maximum mangrove area of 10 km^2 *Sonneratia* sp. has a storm protection value of $15,940,572 at mid tide and $14,866,645 at high tide. Although not shown here, wave attenuation, and thus storm protection value for *K. candel*, is always greater at mid tide compared to high tide as well, but the difference is not as dramatic as for *Sonneratia* sp.

These data show the importance of tidal level, mangrove species, and forest area in the valuation process. If linearity had been assumed and only one point representing a certain species had been chosen, the values would have under or overestimated the actual value of the service. Additionally, these data highlight the need to take non-linearities into account when making management decisions. For example, if only part of the 10 km^2 mangrove forest is to be restored (<7 km^2), the highest coastal protection value would be provided by *Sonneratia* sp. but if an area larger than 10 km^2 is to be restored, the advantages of planting *Sonneratia* sp. instead of *K. candel* are less clear and may depend on other ecosystem services provided by the species.

Management of coastal protection

Managers of coastal systems seeking to sustain and enhance wave protection for local communities and take advantage of the effects described above, have a number of options available to them: conservation of existing conditions; restoration or rehabilitation of elements which have been lost or damaged; and structural engineering approaches. Each of these can involve both synergistic benefits and/or tradeoffs among the various ecosystem services that coastal systems provide to local communities. The non-linearities in wave attenuation described above accentuate the complexity of coastal management decisions but, at the same time, provide a theoretical framework to generate a quantitative approach to the management decision-making process. The lack of acknowledgement of these nonlinearities, as is often the case when only local, short-term data are available, can result in additional management problems. For example, managers may focus on the spatial extent of mangroves rather than the density of trees in restoration and consequently not gain the full coastal protection they expected.

Conservation is a viable option for managers where biotic structures currently provide wave attenuation benefits to coastal villages, but nonlinearities need to be taken into account when determining the area to be preserved. A complete evaluation of multiple ecosystem services (e.g., Barbier et al. 2008a) can be used to justify conservation decisions and enable non-linearities in service provision to be considered in coastal planning. Where the wave attenuation provided by natural ecosystem components has been lost or impaired, restoration or rehabilitation can be justified by

managers on the basis of before-after studies or the comparison between areas with and without biotic structures. The success of such efforts is influenced by elements of non-linearity in wave attenuation described above – the extent of the restored system, the species planted, the timing of restoration and the density at which it was restored. Additionally, non-linear cumulative effects play a major role in coastal restoration. Key geomorphologic features or communities may be needed to either fully compensate for lost services such as wave attenuation (Figure 4) or to facilitate the re-establishment of a full array of services. For example, in areas with high wave energy, a sill, extensive shoal, coral or oyster reef may be essential for creating wave conditions suitable for less wave tolerant communities. If a key structure that reduces wave energy is lost, seagrasses, mangrove or marshes are threatened and their ability to provide coastal protection may be diminished or lost. Such is the case in Florida where the loss of sand bars led to the loss of seagrasses (Lewis 2002) and in coastal Louisiana where restoration of wave attenuating coastal marshes requires the rebuilding of substrate elevations that allow vegetation to colonize.

For many coastal managers, structural engineering approaches such as seawalls and bulkheads provide the easiest and most certain remedy to protect coastal property, villages, and cities from erosion associated with wave impacts. Breakwaters can simulate the wave attenuation function of natural communities by diminishing wave energy before it reaches the shore, while barriers further inland can directly protect coastal infrastructure. Indeed, in some areas, placing hard structures above the high water level to 'hold the line' can be easier to implement than ecosystem based solutions as permitting requirements outside (or inland) of the 'coastal zone' are less stringent (NRC 2007). However, engineered approaches rarely consider the indirect costs in terms of loss of other ecosystem services associated with loss of natural habitat. Thus, wave protection using engineered structures can result in conflict among various ecosystem services (i.e., wave protection *or* nutrient uptake) whereas conservation or restoration approaches can provide for synergies (i.e., wave protection *and* nutrient uptake). By considering spatial and temporal nonlinearities in wave attenuation in EBM practices, better answers may be provided, errors may be reduced and unnecessary or over-engineered wave attenuating structures may be avoided.

Conclusions and Recommendations

Ecosystem functions such as wave attenuation not only have a magnitude but they are also highly dynamic, changing over both space and time predominantly in a non-linear way. The ecosystem service of coastal protection is also non-linear and dynamic. Although there are general commonalities in wave attenuation processes between plant communities (e.g., in Figure 2D), we show that there are many important factors such as plant density and location, species, tidal regime, seasons, and latitude that can influence the types of relationships produced. As a result, temporal and spatial nonlinearity as well as cumulative effects in wave attenuation must be accounted for if we are to accurately estimate the value of coastal protection and to consider it in management decisions. We thus call for a new field in EBM where environmental management decisions are based on the quantification of nonlinearities in ecosystem functions and services. To accomplish this goal, we recommend the following: 1) new and existing data on the functional characteristics of coastal habitats that provide important services to humans needs to be collected and/or synthesized – data gaps, especially in comparative studies, exist; 2) data need to be analyzed to better understand the types of functional relationships and how they might be mitigated by variability in space and time – dynamic ecological models may be needed to account for multiple non-linearities over time and space and cumulative effects; 3) the assumptions of linearity in the valuation of ecosystem services need to be tested - as we have found for coastal protection, this assumption is highly inaccurate; 4) the relevance of non-linearity at different spatial and temporal scales in the ecosystem service valuation process needs to be evaluated – sensitivity analysis is critical; 5) the value of ecosystem services needs to be incorporated into management decisions to maximize, to the largest possible extent, the services provided; and 6) methods used to elucidate the mechanisms controlling ecosystem functions should now be applied to the nascent field of EBM. We suggest that the combination of dynamic ecological modeling, greater field-based testing of the functional relationships of ecosystem services, and economic valuation of those services will increase our accuracy in valuing coastal ecosystems and, in turn, refine EBM practices. Collaboration between economists and ecologists is of the essence in this process. We

call on economists to use existing dynamic models of coastal systems for future economic valuation and on ecologists to fill knowledge gaps on the functional characteristics of coastal habitats that provide ecosystem services. Given the dominance of nonlinearity in the generation of the ecosystem service of coastal protection, we expect nonlinearity to be the common functional relationship for many other ecosystem services as well.

Acknowledgements

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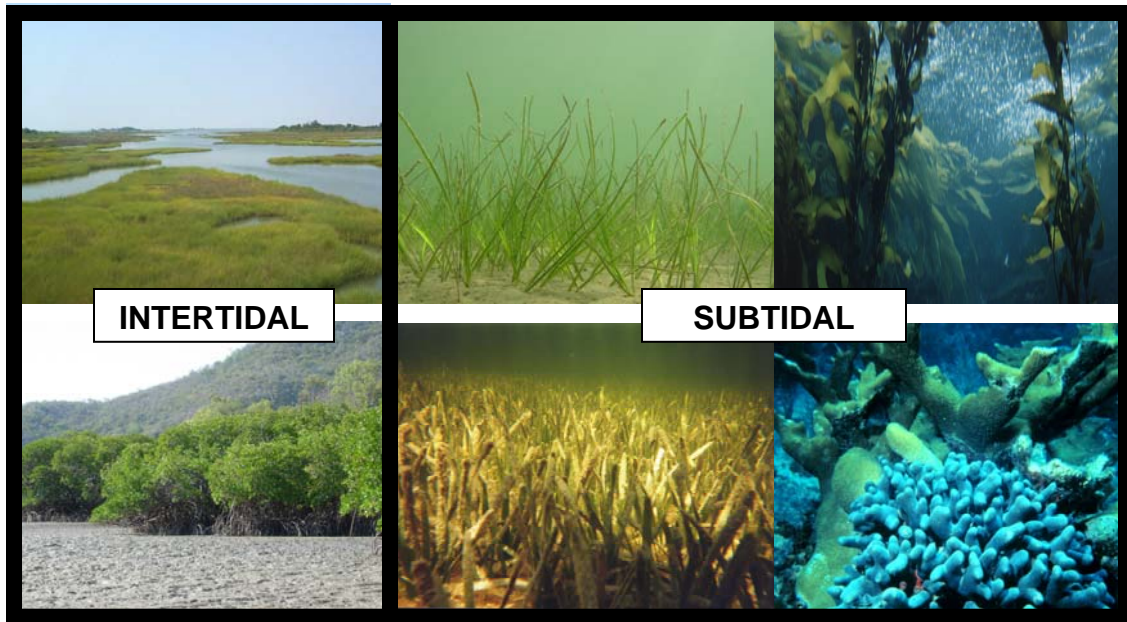
Figure Legends

Figure 1. Examples of biotic structures that attenuate waves in temperate (top - marshes, seagrasses and kelp) and tropical (bottom – mangroves, seagrasses and corals) intertidal and subtidal coastal areas. Note that corals are often necessary to create sheltered conditions suitable for mangrove and seagrass growth. As such, coral reefs contribute directly and indirectly to coastal protection. Source of kelp and coral photos: http://www.mbari.org/ and http://www.photolib.noaa.gov/, respectively.
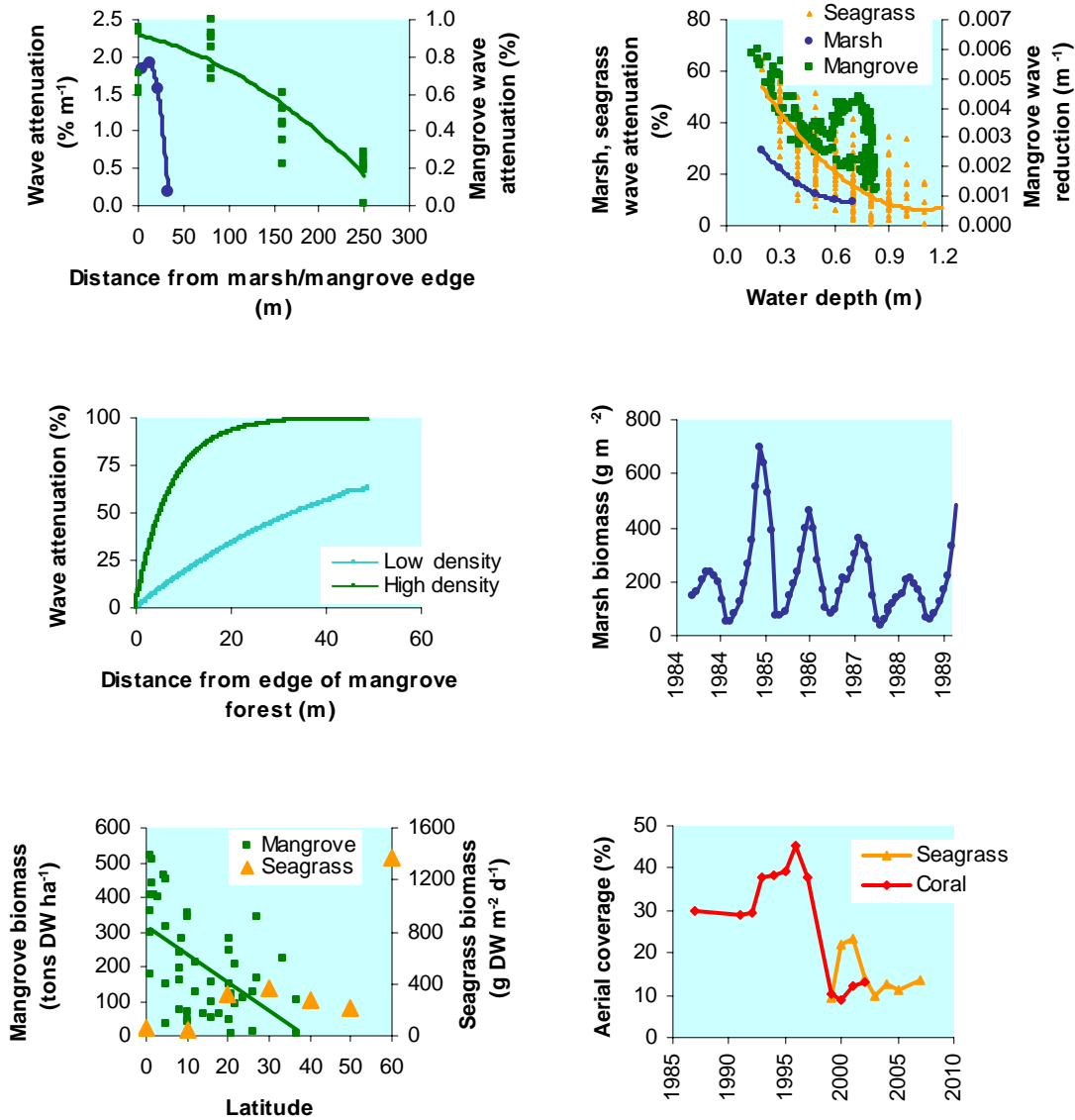
Figure 2. Examples of non-linearities in wave attenuation. Direct measurements of wave attenuation only exists for the smallest spatial (A, Moller 2006 and Massel et al. 1999) and temporal (D, Chen et al. 2007, Moller 2006, Mazda et al. 2006) scales. Wave attenuation for different mangrove densities (B) has been modeled (Massel et al. 1999). Latitudinal wave attenuation is estimated based on the above ground biomass of mangroves (Twilley et al. 1992) and seagrasses (Duarte and Chiscano 1991), i.e. obstructions to water flow (C). Wave attenuation over different seasons is also assumed to change with marsh aboveground biomass (E; Morris and Haskin 1990). Inter-annual variability in corals (modified from McClanahan *et al*. 2005) and seagrass (Merkel 2008) aerial cover (F) is used to estimate long term trends in wave attenuation.
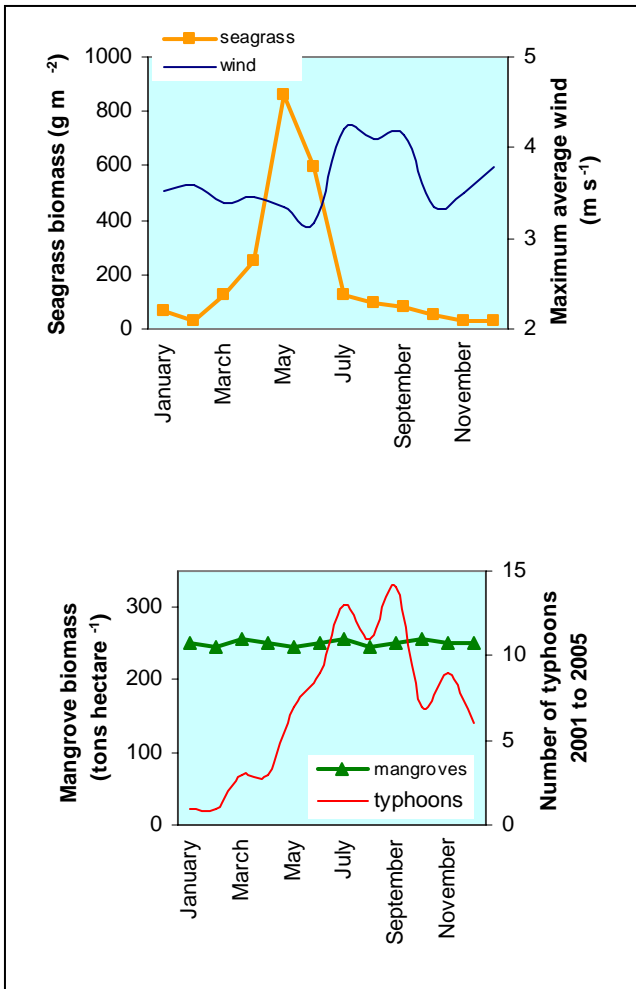
Figure 3. Timing of forcing events affect the value of ecosystem services provided. Biomass of coastal plant communities is highly variable/seasonal in temperate areas (top) while in tropical areas biomass is relatively constant (bottom). Maximum wave attenuation (a.k. maximum biomass) in a seagrass (*Zostera marina*) beds in Korea does not coincide with the time of strongest winds. Therefore, the value of this ecosystem function is diminished. In contrast, biomass in a mangrove forest (Tam et al. 1995) is relatively constant over time. As a result, independent of the timing of storm events, maximum coastal protection is provided throughout the year.
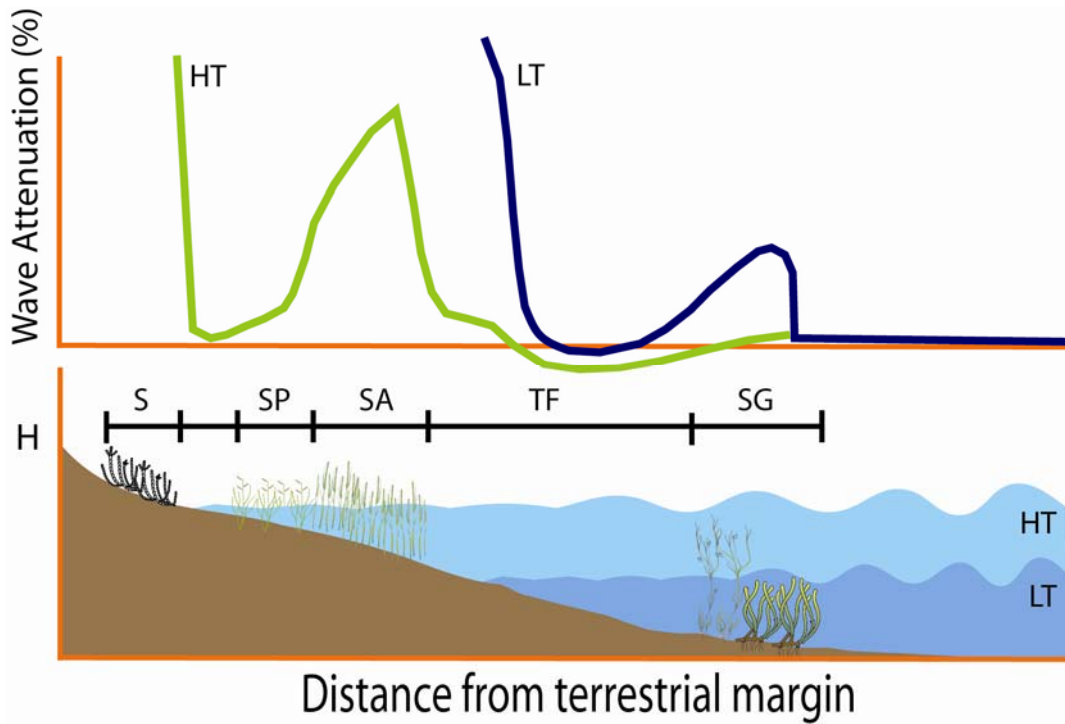
Figure 4. Schematic representation of wave attenuation (%) at high (HT) and low (LT) tide over and idealized temperate coastal wetland during non-extreme events. For the purpose of integration, we added a suite of plants that may not co-occur in nature, but can provide an idea of the cumulative effect they may have on wave attenuation. Note that coastal biotic structures contribute to wave attenuation only when submersed. When marshes, mangroves and seagrasses are exposed at low tide, they do not provide the ecosystem function of wave attenuation. Even so, during low tide, they may still contribute to coastal protection via sediment stabilization. In the figure, we incorporate the geomorphologic effect resulting in wave shoaling, wave regeneration and wave breaking which leads to 100% wave attenuation. In the present case we are not considering the effects of wave surf, run up/backwash, or the dampening of potential high turbidity situations (i.e., fluid mud). SG = seagrass, TF = tidal flat, SA = *Spartina alterniflora*; SP = *Spartina patens*, S = *Salicornia* marsh.
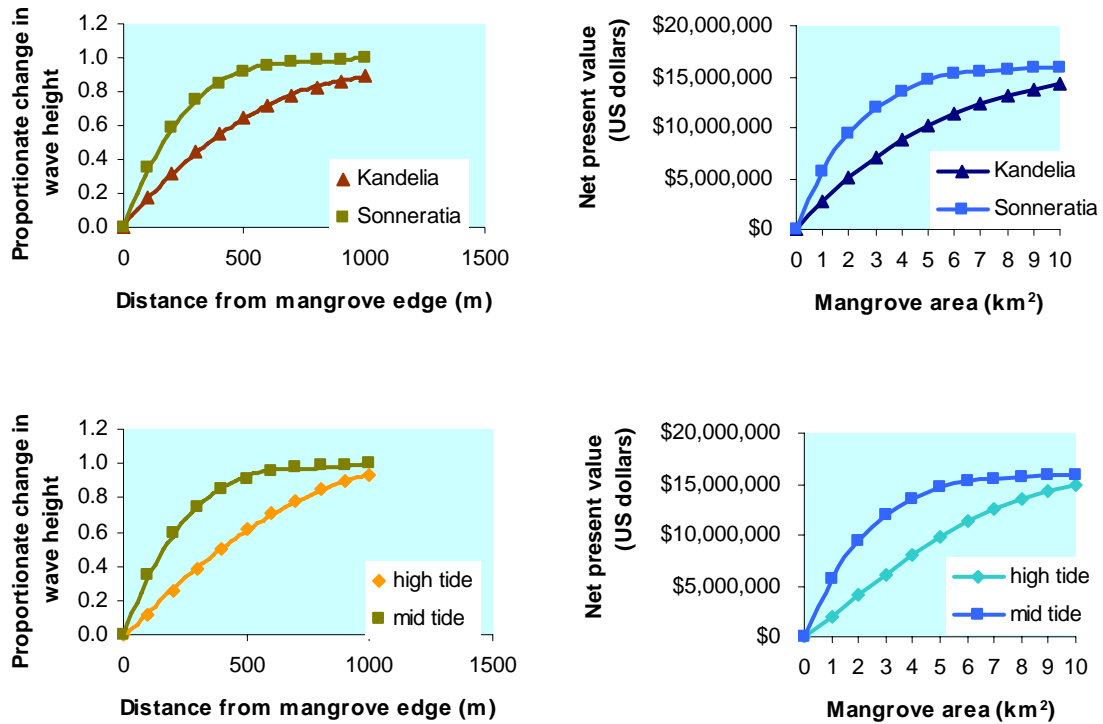
Figure 5. Wave attenuation by mangrove forests is a function of the distance from the seaward edge, and varies by species (A) and tidal stage (C). See the supplementary online material accompanying Barbier et al. (2008a) for methods. As a result, the value of the ecosystem function provided by mangrove forests (net present value, 10% discount rate, 1996$) also varies by species composition (B) and tidal phase (D). The point estimate employed for calculating the value of storm protection is the marginal value per km^2 of $1,599,684 (net present value, 10% discount rate, 1996$) estimated in Barbier (2007). Wave attenuation for mangroves is based on data from Mazda et al. (1997, 2006) and Wolanski (2007) at the coast of Vietnam where *Kandelia candel* and *Sonneratia* sp. mangrove plantations have been created over a wide intertidal shoal as a coastal defense against typhoon waves.