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Fisheries in a Changing Delta

James H. Cowan Jr., Linda A. Deegan and John W. Day

Abstract

Numerous investigations have demonstrated relationships between fisheries yields and the high primary productivities typical of estuaries and estuarine plume ecosystems. Along with the loss of wetlands, presumably so go functions related to them such as commercial harvests of fisheries. However, perhaps the most perplexing aspect of the Mississippi River delta ecosystem is the fact that there is little indication that fisheries productivity has decreased. Why aren't landings decreasing? We favor the explanation that fisheries of today reflect a degraded ecosystem attributable to environmental damages that began in the 1920s or earlier but that accelerated during the twentieth century. There are a few thorough reviews of differential use of habitat by estuarine fishes from other deltaic ecosystems that may allow us to speculate about how the loss of habitat in Louisiana may impact fisheries production. Greater than 75 % of the species that support fisheries in Louisiana are considered to be estuarine-resident or -dependent, and therefore it is likely to end badly for the Sportsman's Paradise if large-scale restoration is not possible, or if possible, not undertaken. Large-scale restoration will cause shifts in the locations of the major fisheries but it may be the only hope of maintaining sustainable fisheries.

Keywords

Fisheries landings · Trophic transfer · Habitat change · Primary productivity · Estuarine ecosystem

Introduction

A number of investigations have demonstrated relationships between fisheries yields and the high nutrient loads, freshwater inputs, shallow depths, large areas of tidal mixing, coastal vegetated area, surface of lagoon-estuarine systems, and resulting high primary productivities that are typical of estuaries, and estuarine plume ecosystems (see Deegan et al. 1986; Nixon 1988; Iverson 1990; Sanchez-Gil and Yáñez-Arancibia 1997; Yáñez-Arancibia et al. 2004). Thus, despite the small aggregate spatial extent of estuaries (<1 % of the global marine area), a fraction exceeding 50 % of U.S. marine fishery yields have historically been derived from estuarine or estuarine-dependent species (Gunter 1967; McHugh 1967; Houde and Rutherford 1993; Vidal-Hernandez and Pauly 2004). In the Gulf of Mexico (hereafter Gulf), the fraction is considerably higher (Houde and Rutherford 1993); estuarine-dependent species dominate in large and valuable commercial and recreational catches (e.g., gulf menhaden *Brevoortia patronus* support the second

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largest U.S. fishery by weight, penaeid shrimps support the fifth largest by value, with shrimp landings alone valued at $ 400–500 million per year).

A large fraction of the harvested secondary production in the Gulf's 'fertile crescent' is derived from estuarine ecosystems, including areas on the shallow shelf influenced by estuarine plumes (Darnell 1990; Christensen and Pauly 1993; Chesney and Baltz 2001; Sanchez-Gil and Yáñez-Arancibia 1997; Day et al. 2004). Characteristic of these estuaries are high river discharge rates, large freshwater surpluses, low water residence times, and large wetland areas. This suggests that much of the production and subsequent trophic transfer may occur outside of the physical boundaries of the estuaries, i.e., in association with plumes of freshwater over shallow continental shelves. These contrasting mechanisms of trophic delivery to the fishery forage base, and ultimately to larger consumers (i.e., estuary versus shelf) introduce uncertainty in how we view the functionality of estuaries and the shelf ecosystems they influence.

Disentangling the relative contributions to fisheries production of estuarine vs. estuarine-like inner shelf ecosystems may be key to long-term resource management, especially in light of rapidly changing conditions. For example, the Mississippi River delta is a complex system including vast areas of water bodies and wetlands (~15,000 km^2 of wetlands alone) in which the rate of land loss has reached catastrophic proportions. Within the last 50 years, land loss rates have exceeded 103 km^2 per year, and in the 1990's the rate has been estimated to be between 65 and 90 km^2 per year. This loss represents about 80 % of the coastal wetland loss in the continental United States. The reasons for wetland loss are complex and vary across the state (e.g., Day et al. 2007). Since the scale of the problem was recognized and quantified in the 1970's, much has been learned about the factors that cause marshes to change to open water and that result in barrier island fragmentation and submergence. The effects of natural processes like subsidence and storms have combined with human actions at large and small scales to produce an ecosystem that may be on the verge of collapse. If recent loss rates continue into the future, even taking into account current restoration efforts, then by 2050 coastal Louisiana will lose more than 250,000 additional hectares of coastal marshes, swamps, and islands. The loss could be greater, especially if worst-case scenario projections of sea-level rise and other climate forcings like increased hurricane intensity are realized (e.g., Blum and Roberts 2009), but in some places there is nothing left to lose. Along with the loss of wetlands, presumably so goes the loss of the various functions and values associated with them: commercial harvests of fisheries, furbearers and alligators; recreational fishing and hunting, and ecotourism; habitats for threatened and endangered species; water quality improvement; navigation corridors and port facilities; flood control, including buffering hurricane storm surges; and the intangible value of land settled centuries ago and passed down through generations. The public use value of this loss is estimated to be in excess of $ 37 billion by 2050 (LCWCRTF 1998; NRC 2006a). As such, we may be shooting at a moving target with respect to understanding ecosystem function (including fishery ecosystems), with large scale and rapid changes in fish habitat (much of which is human-induced) occurring against the backcloth of longer time-scale changes attributable to a variety of anthropogenic insults, climate change, and natural delta cycles (Kennedy et al. 2002; NRC 2006a).

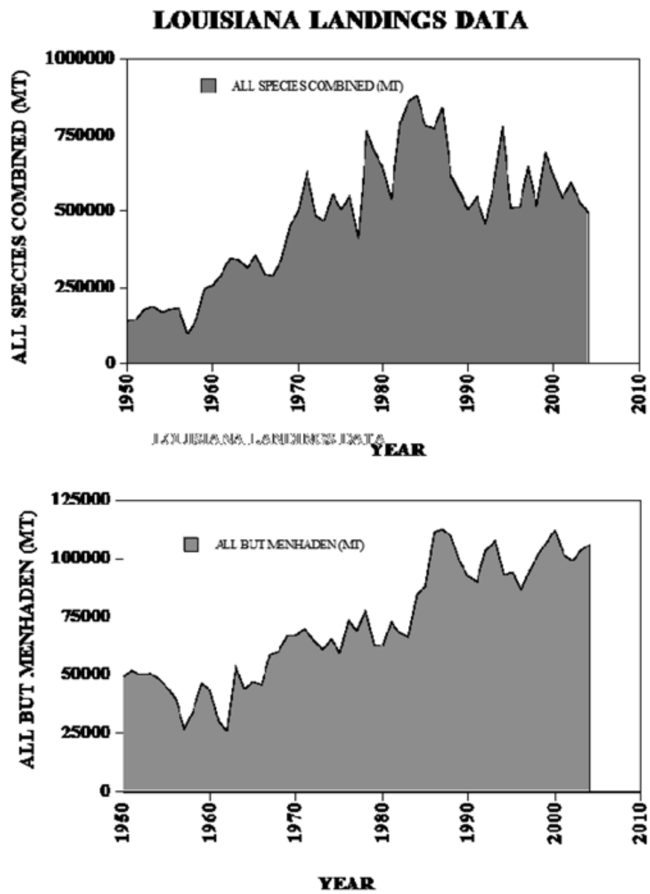
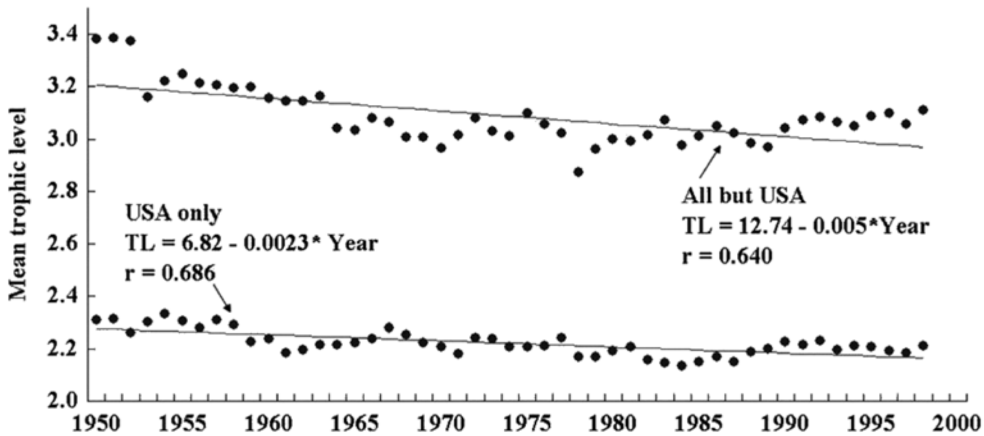


Fig. 1 *Top*. Louisiana commercial landings in metric tons, all species combined. *Bottom*. Louisiana commercial landings excluding gulf menhaden and penaeid shrimp (data from NMFS 2006)

Trends In Louisiana Fisheries

Perhaps the most perplexing aspect of the Mississippi River delta ecosystem, given environmental insults that the system has and continues to endure, is the fact that there is little indication that fisheries productivity has decreased. In fact, the opposite appears to be true if fishery landings (yields) reflect a true measure of productivity, especially if Gulf men-

Fig. 2 The mean trophic level index for Caribbean (non-US) and combined Gulf of Mexico and South Atlantic (US only) commercial fisheries. Gulf of Mexico landings dominate the catches in the US region depicted



haden are excluded from catch statistics (Fig. 1). Declines in menhaden catches since the mid-1980s are largely due to changes in fishing regulations. Landings for all other species combined have increased over the period of record. Reasons for this apparent dilemma were discussed by Chesney et al. (2000), and we will not repeat this discussion beyond addressing some new findings that have appeared in the literature since the aforementioned paper was published.

The most significant of the new studies was published by Pauly and Palomares (2005) in which they calculated the Mean Trophic Level Index (Pauly et al. 1998) for Gulf of Mexico commercial fisheries. Briefly, the index is a biomass-weighted estimate of the mean trophic level of all species included in the commercial capture fisheries in a water body, with a declining slope over time in the index purported to indicate serial overfishing. While there has been significant debate over the value of this index as indicator of ecosystem health (NRC 2006b), the Gulf of Mexico index is worthy of discussion (Fig. 2, from Pauly and Palomares 2005).

The Gulf situation is not notable because the index declines slowly through time as it does in most locations; rather it is notable because the index begins at a y-intercept (~2.3) that is much lower than for other seas (3–4). Pauly and Palomares (2005) concluded that this difference was attributable to a highly degraded food web in which the largest predators had long since been removed by fishing. One alternative interpretation is that the ecosystem supporting Gulf fisheries is so highly degraded that it can no longer support members of the food web at its apex.

Truthfully, neither of these explanations are easily defended because Gulf fisheries, of which ~75% are landed in Louisiana, have historically been dominated by gulf menhaden, which consume phytoplankton, and by penaeid shrimps, which are primarily detritivores (both of these taxa are assumed to be estuarine dependent). Thus a low mean trophic level index is a foregone conclusion for Gulf commercial fisheries if menhaden and shrimp are included in the calculations (De Mutsert et al. 2008). This interpretation is supported by the findings of Chesney et al. (2000) who detected only minor changes in the relative contribution of the species that make up the commercial landings exclusive of menhaden and shrimp, with only a slight increase in the relative abundance of these species thought to be less dependent on coastal wetlands as nursery habitat. The latter finding may be attributable, in part, to high numbers of demersal fishes (mostly juveniles) that are removed via bycatch in the Gulf shrimp fishery each year (see review by Diamond 2004). However, bycatch now is declining through time, and declines are attributable to improvements in efficiency of the shrimp fleet via technological changes and bycatch reduction measures, and significant declines in shrimp fishing effort due to high fuel prices and the low price of imported shrimp, especially since 2002. As such, groundfish biomass in the shallow Gulf has increased four-fold since 2002 (Blue line in Fig. 3), illustrating how difficult is the task of isolating environmental effects from the effects of fishing even for species that are not targeted.

It should be obvious by now that we do not understand how the Mississippi River plume ecosystem directly affects fisheries productivity, exclusive of habitat links to coastal wetlands that were created by the natural delta cycle (Day et al. 2000; NRC 2006a), beyond speculating that recruitment somehow is enhanced by the estuarine plume, which is a plausible hypothesis given the obvious high numbers of juvenile estuarine-dependent fishes found both on the shelf and in the estuaries. We also note that the life histories of the most important commercial species (menhaden and shrimp) favor resilience in the face of fishing pressure (Rose et al. 2001), and are essentially annual crops.

That said, the current configuration of the Mississippi River is artificial and represents a human-induced interruption of the natural delta cycle that began in a major way after flood control measures and farming practices were altered in response to the 1927 flood (NRC 2006a). These changes have resulted in reduced sediment loads in the river proper, and in a river that now discharges far offshore on the edge

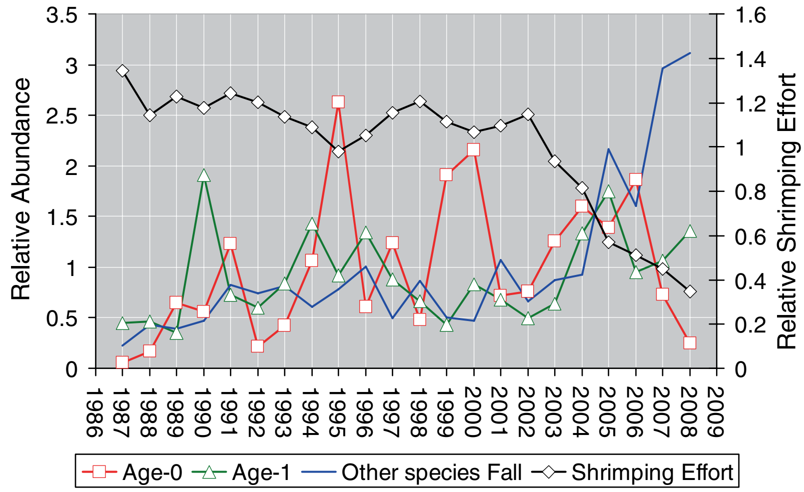


Fig. 3 Relative abundance of age-0 and age-1 red snapper and total biomass of other species captured in the SEAMAP fall ground fish survey. Also shown is relative shrimping effort, which has been declining rapidly since 2002. (W. Ingram, NOAA Fisheries, Mississippi Laboratories, Pascagoula)

of the continental shelf (Day et al. 2000, 2007; NRC 2006a; Blum and Roberts 2009). Both have been linked the high rates of wetland loss attributable to deprivation of nutrients and sediments lost to the offshore environment. These changes, and others, likely also have contributed to hypoxia, and have been punctuated by significant hydrological changes (including saltwater intrusion) that began in earnest with oil and gas exploration in the 1930s and 1940s (LCWCRTF 1998; NRC 2006a) and the impacts of large north-south navigation channels such as the Mississippi River Gulf Outlet and the Calcasieu Ship Channel (Day et al 2000; Shaffer et al. 2009a). Saltwater intrusion has been directly linked to wetland loss (Shaffer et al. 2009b).

So why aren't landings decreasing? One explanation is that Pauly and Palomares (2005) are correct; fisheries productivity, while still high, reflects food web changes that occurred before the period of record. This may be true, but we do not believe that fishing is the likely cause of change. Rather, we favor the alternative explanation mentioned earlier—namely that the fisheries of today reflect a degraded ecosystem attributable to environmental insults that began in the 1920s or earlier but that accelerated during the twentieth century. Recruitment is the most obvious link to biomass and yields, but we have no real evidence that recruitment is limited and/or declining. Table 1 provides a short list of other factors that could be important, some of which have already been discussed.

As can be seen, it is striking that all of the factors listed may have both negative or positive/neutral effects. This may at first seem counterintuitive, but the explanations are quite simple. For example, consider wetland loss. The alteration of flow regimes in large river ecosystems and losses of emergent and submerged aquatic vegetation is a chronic problem worldwide and by no means unique to Louisiana (Nilsson et al. 2005; Syvitski et al. 2009; Voorsmarty et al. 2009). Evidence suggests that fishery landings

Table 1 Factors that contribute to or obscure the relationship between ecosystem health and changes in fisheries productivity. These factors can have both positive or negative effects depending upon the species in question

Wetland loss and habitat modification
Hypoxia and eutrophication
Fishing impacts/bycatch
Climate change

are correlated with the spatial extent of estuarine vegetation (Doi et al. 1973; Deegan et al. 1986; Pauly and Ingles 1988; Chesney et al. 2000). "Indeed, the role of these nearshore ecosystems as nurseries is an established ecological concept accepted by scientists, conservation groups, managers, and the public and cited as justification for the protection and conservation of these areas…. The ecological processes operating in nursery habitats, as compared with other habitats, must support greater contributions to adult recruitment from any combination of four factors (1) density, (2) growth, (3) survival of juveniles, and (4) movement to adult habitats… " (Beck et al. 2001, pp. 633–635). Interestingly, these criteria established by wetland ecologists and managers clearly echo NOAA's National Marine Fisheries Service (NMFS) criteria for establishing essential fisheries habitat (EFH).

However, the relationship between fishery production (yields) and the loss of salt marsh habitat, however, is not clear, and we have already shown that Gulf landings appear to be increasing in spite of accumulating habitat losses (Zimmerman et al. 1989, 1991). One potential hypothesis is that marsh edge, i.e., perimeter, is the critical habitat for many species and that the nursery ground function/value will not decline or result in reduced landings until the quantity of marsh-edge perimeter declines. During marsh loss, the amount of marsh edge initially increases and then declines as healthy marsh is converted to broken marsh and then to open water. The transitory increase in marsh-edge perimeter, which occurs in the marsh break-up phase, may mask the immediate impacts of habitat loss on landings (Browder et al. 1985, 1989). Another related hypothesis postulates that marsh edge is not the critical habitat per se, but serves as the essential conduit for critical trophic exchanges with the flooded marsh (Zimmerman and Minello 1984; Hettler 1989; Chesney et al. 1990; Rakocinski et al. 1992; Baltz et al. 1993; Minello et al. 1994). So it is possible that marsh loss is actually having a positive impact, at least for now.

Eutrophication leads to hypoxia, but increased inorganic nutrient inputs have been to shown to increase fisheries yields as primary productivity is stimulated (Nixon 1988; Iverson 1990) from oligotrophy to mesotrophy, but yields can decline under eutrophic and/or dystrophic conditions, often rapidly (Caddy 1993). The latter situation can also result in increases in abundances of trophic dead ends such as gelatinous zooplankton that prey on fish early life history stages (Cowan and Houde 1992; 1993), thus exacerbating the decline. It is interesting to consider that increasing energy cost may increase the cost of fertilizer so much that hypoxia will be reduced because of lower fertilizer use.

Fishing impacts also have been discussed, but groundfish biomass in the Gulf is now increasing. Many of the species taken in the bycatch are estuarine-dependent, illustrating the difficulty of trying to tease an environmental signal from the backcloth of overexploitation.

Climate change too can have both positive and negative impacts. Worldwide, the fisheries for penaeid shrimps are highest nearer the equator than at the latitude of Louisiana (Kennedy et al. 2002), so modest increases in water temperatures may improve yields in this valuable fishery. However, in a study of factors that regulate benthic food webs in the tropical Fly (Papua New Guinea) and Amazon River deltas and adjacent shelf areas, Alongi and Robertson (1995) found that low food abundance can limit secondary production in areas near river mouths that are exposed to high sedimentation rates.

Historically, coastal wetlands in Louisiana have been dominated by *Spartina* sp. (and *Phragmites* sp. in the fresher Mississippi and Atchafalaya River deltas). Recently, however, black mangroves (*Avicennia germinans*) have expanded and proliferated along Louisiana's coastline due to lack of killing freezes, which in the past occurred on average every 4 years, but last occurred in 1989 (i.e., 22 years ago). By the end of the twenty-first century, tidal, saline habitat is likely to be dominated by mangroves rather than salt marsh if, that is, sea-level rise and hurricanes do not completely eliminate intertidal saline vegetation. Fisheries ecologists once widely assumed that both Spartina and black mangroves provided equally valuable nursery habitat (Manson et al. 2005) and that primary production from both habitats was readily transferred to higher trophic levels (Odum and Heald 1975). This paradigm, however, has been seriously challenged, with indications that mangrove detritus may not be contributing significantly to basal resources, and that decapods and finfishes use of all mangrove habitats may not be equally advantageous across habitat types and latitudes (Rodelli et al. 1984; Hatcher et al. 1989; Fleming et al. 1990; Chong et al. 1990; Hoss and Thayer 1993; Lee 1995; McIvor and Smith 1995; Marguillier et al. 1997; Sheridan and Hays 2003). Thus, the continued expansion of black mangroves has unknown consequences concerning nursery ground function and fisheries productivity in Louisiana.

Climate change threatens practically all coastal wetlands of the Mississippi delta due to the combined impacts of rising sea level, by as much as a meter or more, and salinity intrusion. Blum and Roberts (2009) projected loss of essentially all Mississippi delta wetlands by 2100 due to rising sea level and reduction of sediments in the river. This projection used the IPCC projection of eustatic sea-level rise of about 50 cm. This is less than half of more recent estimates (Rahmstorf et al. 2007; Vermeer and Rhamstorf 2009). Thus, practically all intertidal habitat used by fishery species will likely be gone by the end of the century unless there is an aggressive restoration program.

Complicating climate impacts are potentially dramatic increases in the cost and availability of energy. Rising fuel costs are already affecting fishing and continued increases may make fishing as presently carried out unsustainable. It is unclear how the fishing industry can adapt to these challenges. On the other hand, increased energy cost may make the cost of imports more expensive compared to local fisheries. For example, when oil prices reached nearly $ 150 a barrel, the U.S. steel industry became competitive with Chinese imports because of increased shipping costs. It may be that fisheries will have to change to more energy efficient methods

The Future of Louisiana Fisheries—Examples from Other Deltaic Ecosystems

It should be clear from the prevarication in the preceding paragraphs that is very difficult to guess, let alone predict, how fisheries productivity in Louisiana and the northern Gulf will change in response to aforementioned factors. Unfortunately, studies elsewhere provide little insight, as there are few comprehensive studies of secondary and tertiary productivity in deltaic ecosystems worldwide. But where they have been undertaken the most common injuries to fisheries productivity (or changes in species composition) are related to changes in river flow, and do not disentangle the effects of habitat change in the delta proper from changes in adjacent shelf areas (e.g., Leslie and Timmins 1991; Grimes 2001; Cowan et al. 2008). This is true in the Danube, Ebro, Niger, Nile, Po, Rhone and Colorado River Deltas where upstream changes in land use, and the construction of dams have resulted in decreases in fisheries productivity, changes in species composition, and or greater susceptibility to colonization by invasive species (Lumarea et al. 1993; Lae 1994; Lae 1995; Galindo-Bect et al. 2000; Wilson 2002; Elliot and Hemmingway 2002; Salen-Picard et al. 2002; Holcik 2003; Lloret et al. 2004). Few of these studies relate observed changes to loss of vegetated wetlands although Galindo-Bect et al. (2000) implicate habitat loss in the decline of the penaeid shrimp fishery in the Gulf of California.

That said, there are a few thorough reviews of differential use of habitat by estuarine fishes (Wilson 2002; Pihl et al. 2002; Costa et al. 2002; Nordlie 2003) that may allow us to speculate about how the loss of habitat in Louisiana may impact fisheries production. We believe, as do the authors of the aforementioned reviews, that it is not useful to consider the impacts of coastal wetland loss independently from other habitats in the estuarine ecosystem. To illustrate this point, we provide a cogent example found in Pihl et al. (2002). In their comprehensive review of European estuaries, they identify nine distinct habitat types in estuarine ecosystems, and then combine form (habitat type) and function (usage) in a useful semi-quantitative index of habitat utilization that includes habitat use by life history stage (eggs, larvae, juveniles and adults). This takes into account whether the fishes are estuary residents or transients, and also includes diadromous species that often migrate through an estuary to spawn as adults, while both adults and early life history stages can migrate out. The Habitat Utilization Index (HUI) is the sum of life history stages using a single habitat divided by the number of sites for that habitat in all estuaries combined. This index approximates the overlap between fish life history stages and the overall usage of each habitat type and their results are shown in. Table 2.

Table 2 The Habitat Utilization Index (HUI) calculated for European estuaries. The index represents the sum of fish life history stages using a single habitat divided by the number of sites for that habitat in all estuaries combined. (Pihl et al. 2002)

Habitat/Number	HUI
Tidal freshwater	23.1
Reed beds (2)	15.5
Saltmarsh (3)	19.3
Intertidal soft substrate (4)	37.6
Intertidal hard substrate (5)	9.0
Subtidal soft substrate (6)	69.7
Subtidal hard substrate (7)	43.3
Subtidal sea grass beds (8)	46.5
Biogenic reefs (9)	20.7

The HUI evaluates a habitat on the basis of an average number of uses made by all species and all life stages. The results are: subtidal soft > subtidal sea grass > subtidal hard > intertidal soft > tidal fresh > biogenic reefs > saltmarsh > reed beds > intertidal hard. It should be apparent by now that habitat complexity is only one part of the equation that determines the relative value of a particular habitat type to estuarine nekton. The HUI also does not sum to 100 %, stressing the fact that estuaries should be viewed as a matrix of interconnected habitats that can used by many species for the same or different functions, and for any single species, can used be used for different functions depending upon their life history stage.

The habitat attribute that is most important to use by estuarine nekton is the frequency of inundation, i.e., how often the habitat covered by water. Habitats that are always flooded are the habitats that are most well utilized by estuarine fishes and other nekton species Among the habitats that are always flooded, subtidal soft substrate is the largest by areal extent, but also provides excellent feeding and nursery grounds for estuarine nekton. The structural complexity of subtidal sea grasses and subtidal hard substrate also is important both for feeding and refuge, showing that habitat complexity is an important attribute as well. Use by nekton in terms of habitat type and function does not vary significantly with latitude, suggesting that strong local gradients in factors such as temperature and salinity, or high variability among a variety of factors, create conditions to which relatively few species, excepting estuarine residents and dependents, can easily adapt.

While we have not made HUI calculations for Louisiana's deltaic habitats, only intertidal hard substrate among the nine identified by Pihl et al. is mostly lacking in Louisiana, and we believe that if calculations were done here, they would resemble those from Europe. This example, and our own research experience, suggest to us that changes in the coastal landscape that lead to continued wetland loss (or in our case, failure to change) will not act solely on wetlands, but will likely result in simplification of the estuarine habitat matrix, thus reducing the functional integration of habitat uses. Such changes will benefit some species, and greatly reduce the biomass and productivity of others. In Louisiana's case, the losers are likely to be those species that depend most strongly on, and are most tightly constrained to combinations of habitats found in, the habitat matrix unique to Louisiana's coastal deltaic ecosystem. Given that greater than 75 % of the species that support fisheries in Louisiana are considered to be estuarine-resident or -dependent, it is likely to end badly for the Sportman's Paradise if large-scale restoration is not possible, or if possible, not undertaken.

The Way Forward—Ecosystem Restoration and Louisiana Fisheries

While neither exhaustive, nor a thorough review of the issues identified, the list in Table 1 well illustrates that we may be approaching or have reached an important nexus in the history of fisheries productivity in the northern Gulf of Mexico (Fig. 4). Panel A assumes that the fisheries remain

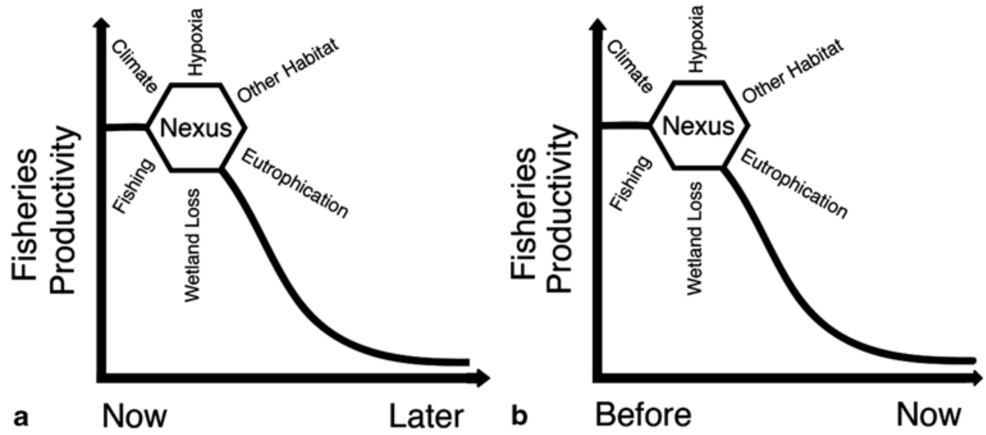


Fig. 4 The history or, perhaps, future of fisheries productivity in Louisiana, and presumed causes for change. Panel A assumes that the fisheries remain intact and near historical highs, but that we may be headed towards a steep decline if cumulative impacts reach a tipping point. Panel B assumes that Louisiana fisheries have already declined below historically higher levels

intact and near historic highs, but that we may be headed towards a steep decline if cumulative impacts reach a tipping point. Panel B assumes that Louisiana fisheries have already declined below some historically higher levels, the cause of which is overfishing, if Pauly and Palomares (2005) are correct. If the latter is true, the path forward may simply be more conservative fishing regulations.

On the other hand, if either Panel A or B is correct, and declines in productivity have been (or will be) attributable to declines in the Mississippi River ecosystem's ability to provide the previously described habitat matrices, the path forward will much more complicated.

Louisiana accounts for 60–80% of the nation's total annual coastal wetland loss, the causes of which are largely anthropogenic and well documented (Boesch et al. 1994; Day et al. 2000, 2007; NRC 2006a). Continued alteration, degradation, and loss of Louisiana's estuarine and wetland habitats, makes knowledge of the relationship between habitat stability, and its affects on nursery ground function and fishery production critical. To confront this issue in Louisiana and elsewhere, concepts of ecosystem management and sustainable development have become part of state, national and international dialogue about adaptive environmental management, as emphasized in the President's Commission Report on the State of the Ocean, the Pew Ocean's Report, and language in the recent Sustainable Fisheries Act. Formulation and implementation of long-term, sustainable coastal policies and integrated management strategies demand a better understanding of: (1) habitat and ecological stability and associated functional responses to both episodic and chronic insults, especially given the limited vitality of already-stressed coastal ecosystems; and, (2) the compounding and complex effects of multiple impacts superimposed on issues associated with shifting baselines and climate change (Jackson et al. 2001).

Issues facing Mississippi deltaic ecosystems are not unique, but Hurricanes Katrina and Rita in 2005 and Gustav in 2008, as well as the Deepwater Horizon oil spill in 2010, which cumulatively caused loss or degradation of many hundreds of square kilometers of coastal marshes, caused Louisiana to renew its commitment to preserve and restore coastal ecosystems in the region by managing the impacts of human activities through the Coastal Wetlands Planning, Protection and Restoration Act of 1990 (CWPPRA), Coast 2050 and Coastal Louisiana Environmental Assessment and Restoration (CLEAR) programs. These initiatives include large-scale sediment diversions, use of wetlands to provide tertiary assimilation of treated municipal effluent and surface runoff, proactive management of wetland water control structures, as well as creative mitigation banking involving habitat enhancement and creation to offset environmental impacts. But the question remains—can we steer a degraded ecosystem towards some alternate steady state that resembles an historical baseline?

It is possible, we believe, that restoration activities that are being proposed in Louisiana may be able to do just that, based primarily upon the assertion that large-scale re-introduction of Mississippi River sediments can significantly shift the ecological baseline back towards pre-storm conditions in the short-term, and towards less degraded baseline conditions in the longer term. However, we recognize the difficulties embodied by this assertion. While recent research (DeLaune et al. 2003; Day et al. 2003; Mitsch et al. 2005; Day et al. 2009; DeMutsert 2010) has buoyed our confidence in the ability to restore degraded wetlands through large-scale sediment diversions, we understand that there are fundamental differences in opinion in the likelihood of long-term success (Howes et al. 2010) that are dependent upon overall system behavior.

One endpoint of the continuum of possible system responses to restoration efforts infers that the Louisiana coastal ecosystem experienced a regime shift when large-scale leveeing began on the Mississippi River, and oil and gas exploration began in earnest. One important characteristic of regime shifts is that they are usually driven by bottom-up processes, such as climate variability and resulting changes

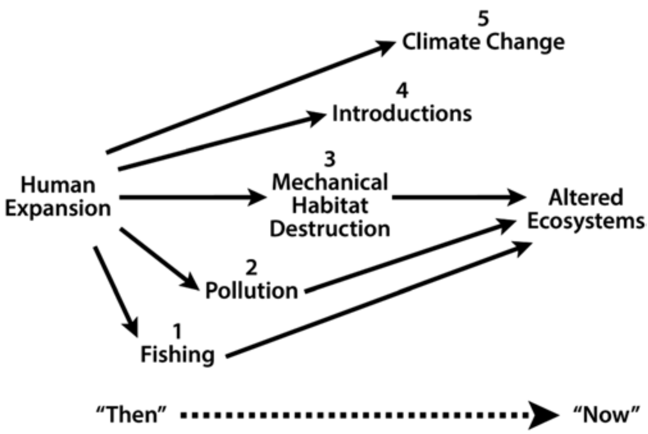


Fig. 5 Examples of top-down controls induced by human expansion resulting in altered ecological baselines. (from Jackson et al. 2001)

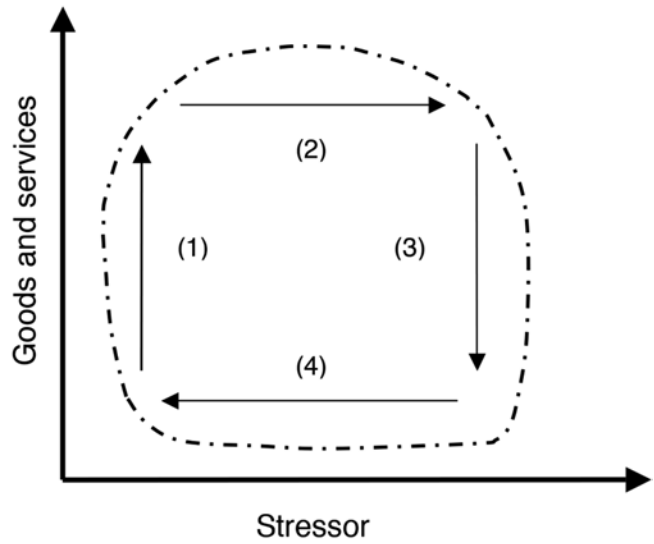


Fig. 6 A hysteresis loop whereby some components of an ecosystem fail to respondthrough time as expected, delaying recovery despite a decrease in stress (Cowan et al. 2008).

in species composition, and in primary and secondary productivity, or by analogy in the case of Louisiana, shifts in the position of the main Mississippi River distributary mouth, and are inherently reversible. Perhaps the most well studied example of regime shifts occur in the eastern Pacific Ocean in response to decadal scale variability in the relative position and strength of atmospheric highs and lows over the north Pacific (i.e., the Pacific Decadal Oscillation). Large-scale climate variability produces bottom-up changes in coastal ecosystems such that during cold regimes, anchovies are favored, and during warmer periods, sardines replace anchovies as the dominant forage species in Pacific Ocean ecosystems (Belda 1999). This type of response is illustrated in a fisheries example by the cycling of anchovy and sardine populations in a variety of locations. It is important to note that after each shift, the ecosystem reverts to an alternate steady state, followed by a recovery of the system to near its previous state prior to the change in climate. If the Louisiana coastal ecosystem responds to restoration as has the north Pacific to climate variability, restoration efforts may produce a nearly linear response in efforts to restore ecosystems goods and services, including fisheries productivity (Walters and Jones 1976).

Another endpoint involves the possibility that the Louisiana coastal zone will respond to restoration efforts in a way that will be more challenging to overcome. In several recent studies it has been shown that human-induced changes in ecosystem function result from top-down effects such as fishing, habitat modifications, pollution, eutrophication, etc., resulting in a shift in the ecological baseline (Jackson et al. 2001, Fig. 5). In such cases, the altered ecosystems are often much less responsive to management actions that attempt to recover ecosystem functionality. This occurs for a variety of reasons ranging from reductions or changes in habitat, to reorganizations of food-webs because of the removal of top predators (NRC 2006b). Regardless of the mechanisms, however, alternate steady states that have been caused by forcing from the top-down may be less likely to return to a state that resembles "pristine", and thus less likely to provide ecological goods and services and fisheries productivity that are similar to pre-disturbed conditions (Jones and Walters 1976).

Perhaps the most notable example of a large-scale shift in the ecological baseline of a fisheries ecosystem occurred on Georges Bank in response to long-term overfishing of ground fish stocks (Rosenberg et al. 2005). In this case, due to extreme top-down forcing attributable both to fishing pressure and habitat alterations from bottom trawling, the Georges Bank food-web reorganized and the more desirable gadoid groundfish complex was replaced by elasmobranches. Despite a tremendous 10-year reduction in fishing pressure, the Georges Bank fishery has failed to recover overall, although the level of recovery is highly species-specific (haddock show recent increases in recruitment while cod remain depressed; Fogarty et al. 2001), illustrating another important aspect of baseline shifts.

In highly degraded systems, species-specific variability in the rate of response to efforts to mitigate and restore man-induced changes in ecosystem function is not uncommon (NRC 2006b). Some species, or even groups of species, exhibit hysteresis and do not respond to management as expected. As illustrated in Fig. 6 (Steele J., personal communication), hysteresis occurs when ecosystem constituents increase rapidly when stress is low (1), reach a stable steady state when available resources are fully utilized or as ecological stressors increase through time (2), and subsequently collapse when stress becomes excessive (3). As suggested by the Georges Bank example, some components of the ecosystem then will fail to recover even (4) as ecological stress is decreases. So the question now becomes—Will the Louisiana coastal ecosystem and its related fisheries productivity respond to restoration efforts as if the region has experienced a regime shift, or a shift in the ecological baseline? Is the distinction important?

We contend that this distinction speaks directly to whether our coastal ecosystems can or cannot be restored, and their fisheries productivity held intact or increased. Moreover, answers to these questions are fundamental to understanding the relationships between fish and marsh habitats, and can only be answered by explicitly linking studies of wetlands functioning to studies of fisheries habitat.

We have reason to be optimistic even though we expect some components of the ecosystem, particularly higher trophic levels, to recover more slowly then others as wetlands are restored (Rozas et al. 2005). Our optimism is based upon the premise that the current degraded condition of Louisiana's coastal wetlands, although driven by human activities from the top down, represents changes that mimic a natural and short, < 100-year interruption in a cycle of delta creation/decay that normally takes hundreds to thousands of years to complete. As such, large-scale restorations efforts to divert Mississippi River sediments back into degraded areas should begin the delta cycle anew and facilitate the "resetting" of prior conditions. This premise also infers that to delay restoration efforts could have important consequences on the likelihood and expected rates of ecosystem recovery.

Projected climate change argues for an aggressive restoration program. If current trends continue, essentially all coastal wetlands will disappear (Blum and Roberts 2009). This outcome would almost certainly lead to significant changes in the nature of fisheries productivity in the Gulf. Kim et al. (2009) report that large-scale sediment diversions on the order of the Wax Lake channel could restore considerable areas of coastal wetlands even with accelerated sea level rise. Large-scale restoration would cause shifts in the locations of the major fisheries but it may be our only hope of maintaining a sustainable fishery.

Increasing energy costs could have both positive and negative benefits for fisheries. Increasing energy costs will likely make imports more expensive and ultimately uncompetitive. This would also make Louisiana fisheries more expensive. But if more energy efficient fishing methods can be used (butterfly nets versus trawling, for example), then a sustainable fishery may be possible. Such a fishery would be different from current fisheries. This is a question that deserves much more thought.

In conclusion, there is much uncertainty how the various factors affecting fisheries interact. Thus far, combined interactions of fishing pressure, habitat loss, and water quality deterioration have not caused a decline in fisheries. It is also uncertain how restoration will impact fisheries.

References

Alongi DM, Robertson AI (1995) Factors regulating benthic food chains in tropical river deltas and adjacent shelf areas. Geo-Mar Lett 15:145–152

Baltz DM, Rakocinski C et al (1993) Microhabitat use by marsh-edge fishes in a Louisiana estuary. Environ Biol Fish 36:109–126

Beck MW, Heck KL Jr., Able KW, Childers DL, Eggleston DB, Gallanders BM, Halpern B, Hays CG, Hoshino K, Minello TJ, Orth RJ, Sheridan PF, Weinstein MP (2001) The identification, conservation and management of estuarine and marine nurseries for fish and invertebrates. Bioscience 51:633–641

Belda LD (1999) The interdecadal climate signal in the temperate large marine ecosystems of the Pacific. In: Sherman K, Tang Q (eds) Large Marine Ecosystems of the Pacific Rim: Assessment, Sustainability, and Management. Blackwell Science, Inc., Hoboken, pp 42–47

Blum MD, Roberts HH (2009) Drowning of the Mississippi Delta due to insufficient sediment supply and global sea-level rise. Nat Geosci. doi:10.1038/NGEO553

Browder JA, Bartley HA, Davis KS (1985) A probablistic model of the relationship between marshland-water interface and marsh disintegration. Ecol Model 29:245–260

Browder JA, May LN Jr., Rosenthal A, Gosselink JG, Baumann RH (1989) Modeling future trends in wetland loss and brown shrimp production in Louisiana using thematic mapper imagery. Remote Sens Environ 28:45–59

Caddy JF (1993) Toward a comparative evaluation of human impacts on fishery ecosystems of enclosed and semi-enclosed seas. Rev Fish Sci 1:57–95

Chesney EJ, Baltz DM (2001) Chapter 17: The effects of hypoxia on the northern Gulf of Mexico coastal ecosystem: a fisheries perspective. In: Rabalais NN, Turner RE (eds) Coastal and estuarine studies: coastal hypoxia-consequences for living resources and ecosystemss. American Geophysical Union, Washington, DC, pp 321–354

Chesney EJ, Baltz DM, Thomas RG (2000) Louisiana estuarine and coastal fisheries and habitats: perspectives from a fish's eye view. Ecol Appl 10:350–366

Chong VC, Sasekumar A, Leh MUC, D'Cruz R (1990) The fish and prawn communities of a Malaysian coastal mangrove system with comparisons to adjacent mud flats and inshore waters. Estu Coast Shelf Sci 31:703–722

Christensen V, Pauly D (1993) On steady-state modelling of ecosystems. Trophic models of aquatic ecosystems (ICLARM Conference Proceedings)

Costa MJ, Cabral HN, Drake P, Economou AN, Fernandez-Delgado C, Gordo L, Marchand J, Thiel R (2002) Chapter 3 Recruitment and production of commercial species in estuaries. In: Elliot M, Hemmingway KL (eds) Fishes in estuaries. Blackwell Science Ltd., Oxford

Cowan JH Jr, Houde ED (1992) Size-dependent predaton on marine fish larvae by ctenophores, scyphomedusae, and planktivorous fish. Fish Oceanogr 1:113–126

Cowan JH Jr, Houde ED (1993) The relative predation potentials of scyphomedusae, ctenophores and planktivorous fish on ichthyoplankton in Chesapeake Bay. Mar Ecol Prog Ser 95:55–65

Cowan JH Jr, Grimes CB, Shaw RF (2008) Life history, history, hysteresis and habitat changes in Louisiana's coastal ecosystem. Bull Mar Sci 83:197–215

Darnell RM (1990) Mapping of the biological resources of the continental shelf. Am Zool 30:15–21

Day J, Shaffer G, Britsch L, Reed D, Hawes S, Cahoon D (2000) Pattern and process of land loss in the Mississippi delta: A spatial and temporal analysis of wetland habitat change. Estuaries 23:425–438

Day JW, Ko J, Cable J, Day JN, Fry B, Hyfield E, Justic D, Kemp P, Lane R, Mashriqui H, Reyes E, Rick S, Snedden G, Swenson E, Templet P, Twilley R, Wheelock K, Wissel B (2003) Pulses: the importance of pulsed physical events for Louisiana floodplains and watershed management. First interagency conference on research in the watersheds. Oct 27–30:693–699

Day JW, Diaz de Leon A, Gonzalez-Sanson G, Moreno-Casasola P, Yañez-Arancibia A (2004) Resumen Ejecutivo: Diagnostico Ambiental del Golfo de Mexico [Executive summary: environmental diagnosis of the Gulf of Mexico], 10 pages. In *Diagnostico Ambiental del Golfo de Mexico [Environmental diagnosis of the Gulf of Mexico]*. INE-SEMARNAT, Mexico DF, 280 pp

Day JW, Gunn JD, Folan WJ, Yanez-Arancibia A, Horton BP (2007) Emergence of complex societies after sea level stabilized. EOS 88:169–170

Deegan LA, Day JW, Gosselink JG, Yañez-Arancibia A, Soberon Chavez G, Sanchez-Gil P (1986) Relationships among physical characteristics, vegetation distribution and fisheries yield in Gulf of Mexico estuaries. In: Wolfe DA (ed) Estuarine variability. Academic Press, Inc., Orlando, pp 83–100

DeLaune R, Jugsujinda A, Peterson G, Patrick W (2003) Impact of Mississippi river freshwater reintroduction on enhancing marsh accretionary processes in a Louisiana estuary. Est Coast Shelf Sci 58:653–662

de Mutsert K, Cowan JH Jr, Essington TE, Hilborn R (2008) Re-analyses of Gulf of Mexico fisheries data: landings can be misleading in assessments of fisheries and fisheries ecosystems. Proc Natl Acad Sci U S A 105:2740–2744

Diamond SL (2004) Bycatch quotas in the Gulf of Mexico shrimp trawl fishery: can they work? Rev Fish Biol Fish 14:207–237

Fleming M, Lin G, Sternberg LSL (1990) Influence of mangrove detritus in an estuarine ecosystem. Bull Mar Sci 47:663–669

Fogarty MJ, Myers RA et al (2001) Recruitment of cod and haddock in the North Atlantic: a comparative analysis. ICES Mar Sci Symp 58:952–961

Grimes C (2001) Fishery production and the Mississippi river discharge. Fisheries 26:17–26

Gunter G (1967) Some relationships of estuaries to the fisheries of the Gulf of Mexico. In: Lauff GH (ed) Estuaries. AAAS Publ. 83, Washington, DC, pp 621–638

Hatcher BG, Johannes RE, Robertson AI (1989) Review of research relevant to the conservation of shallow tropical marine ecosystems. Oceanogr Mar Biol Ann Rev 27:337–414

Hettler WF Jr (1989) Nekton use of regularly-flooded salt-marsh cordgrass habitat in North Carolina, U S A. Mar Ecol Prog Ser 56:111–118

Holcik J (2003) Changes in the fish fauna and fisheries in the Slovak section of the Danube River: a review. Ann Limnol 39:177–195

Hoss DE, Thayer GW (1993) The importance of habitat to the early life history of estuarine dependent fishes. Amer Fish Soc Symp 14:147–158

Houde ED, Rutherford ES (1993) Recent trends in estuarine fisheries: predictions of fish production and yields. Estuaries 16:161–176

Howes NC, Fitzgerald DMZ, Hughes ZJ, Georgiou IY, Kulp MA, Miner MD, Smith JM, Barras JA (2010) Hurricane-induced failure of low salinity wetlands. PNAS 107:14014–14019

Iverson RL (1990) Control of marine fish production. Limnol Oceanogr 35:1593–1604

Jackson JBC, Kirby MX et al (2001) Historical overfishing and recent collapse of coastal ecosystems. Science 293:629–638

Jones DD, Walters CJ (1976) Catastrophe theory and fisheries regulation. J Fish Res Bd Canada 33:2829–2833

Kennedy VS, Twilley R, Kleypas J, Cowan JH Jr, Hare SR (2002) Coastal and marine ecosystems and global climate change. Potential effects on U S resources. Pew Center on Global Climate Change, Arlington Aug 2002. 52 pp

Kim W, Mohrig D, Twilley R, Paola C, Parker G (2009) Is it feasible to build new land in the Mississippi River Delta? EOS Trans AGU 90:373–374

Lae R (1994) Effect of drought, dams and fishing pressure on the fisheries of the central delta on the Niger river. Int J Ecol Environ Sci 20:119–128

Lae R (1995) Clirnatic and anthropogenic effects on fish diversityand fish yields in the central delta of the Niger river. Aquat Living Resour 8:43–58

LCWCRTF (Louisiana Coastal Wetlands Conservation and Restoration Task Force) (1998) Coast 2050: toward a sustainable coastal Louisiana

Lee SY (1995) Mangrove outwelling: a review. Hydrobiol 295:203–212

Leslie JK, Timmins CA (1991) Distribution and abundance of young fish in Chenal Ecarte and Chematogen Channel in the St. Clair River delta, Ontario. Hydrobiologia 219:135–142

Lloret I, Palomera I, Salat J, Sole J (2004) Impact of freshwater input and wind on landings of anchovy (Engraulis encrasicolus) and sardine (Sardina pilchardus) in shelf waters surrounding the Ebre (Ebro) River delta (north-western Mediterranean). Fish Oceanogr 13:102–110

Lumarea F, Di Muro P, Tenderini L, Zupo V (1993) Experimental intensive culture of *Penaeus monodon* in the cold-temperate climate of the North-East coast of Italy (a fishery 'valle' of the River PO Delta). Aquaculture 113:231–241

Manson FJ, Loneragan NR, Skilleter GA, Phinn SR (2005) An evaluation of the evidence for linkages between mangroves and fisheries: a synthesis of the literature and identification of research directions. Oceanogr Mar Biol Ann Rev 43:485–515

Marguillier S, Velda G van der, Dehairs F, Hemminga MA, Rajagopal S (1997) Trophic relationships in an interlinked mangrove-seagrass ecosystem as traced by δ13C and δ15N. Mar Ecol Prog Ser 151:115–121

McHugh JL (1967) Estuarine nekton. In: Lauff GH (ed) Estuaries. American Association for the Advancement of Science, Publication 83, Washington, DC, pp 581–629

McIvor CC, Smith TJ III (1995) Differences in the crab fauna of mangrove areas at a southwest Florida and a northeast Australia location: Implications for leaf litter processing. Estuaries 18:591–597

Minello TJ, Zimmerman RJ, Midina R (1994) The importance of edge for natent macrofauna in a created saltmarsh. Wetlands 14:184–198

Mitsch WJ, Zhang L et al (2005) Creating riverine welands: ecological succession, nutrient retention, and pulsing effects. Ecol Engineer 25:510–527

Nilsson C, Reidy CA et al (2005) Fragmentation and flow regulation of the world's large river systems. Science 308:405–408

Nixon SW (1988) Physical energy inputs and the comparative ecology of lake and marine ecosystems. Limnol Ocean 33:1005–1025

Nordlie FG (2003) Fish communities of estuarine salt marshes of eastern North America, and comparisons with temperate estuaries of other continents. Rev Fish Biol Fisheries 13:281–325

NRC (National Research Council) (2006a) Drawing Louisiana's new map. Addressing land loss in coastal Louisiana. National Academy Press, Washington, DC

NRC (National Research Council) (2006b) Dynamic changes in marine ecosystems. Fishing, food webs, and future options. National Academy Press, Washington, DC

Galindo-Bect M, Glenn EP, Page H, Fitzsimmons K, Galindo-Bect LA, Hernandez-Ayon JM, Petty RL, Garcia-Hernandez J, David M (1999)

Penaeid shrimp landings in the upper Gulf of California in relation to Colorado River freshwater discharge. Fish Bull US 98:222–225
Pauly D, Ingles J (1988) The relationship between shrimp yields and intertidal vegetation (mangrove) areas: a reassessment. In: Yanez-Arancibia A, Pauly D (eds) IOC/FAO Workshop on Recruitment in Tropical Coastal Demersal Communities. UNESCO Intergovernmental Oceanographic Commission Workshop Report 44 Supplement. pp 277–283
Pauly D, Palomares M-L (2005) Fishing down marine food webs: it is far more pervasive than we thought? Bull Mar Sci 76:197–211
Pauly D, Christensen V et al (1998) Fishing down marine food webs. Science 279:860–863
Pihl L, Cattrijsse A, Codling I, Mathiesan S, McLusky DS, Roberts C (2002) Chapter 2: Habitat use by fishes in estuaries and other brackish areas. In: Elliot M, Hemmingway KL (eds) Fishes in estuaries. Blackwell Science Ltd., Oxford
Rahmstorf S, Cazenave A, Church JA, Hansen JE, Keeling RF, Parker DE, Somerville RCJ (2007) Recent climate observations compared to projections. Science 316:709
Rakocinski C, Baltz DM, Fleeger JW (1992) Correspondence between environmental gradients and the community structure of marsh-edge fishes in a Louisiana estuary. Mar Ecol Prog Ser 80:135–148
Rodelli MJ, Gearing JN, Gearing PJ, Marshall N, Sasekumar A (1984) Stable isotope ratio as a tracer of mangrove carbon in Malaysian ecosystems. Oecol 61:326–333
Rosenberg AA, Bolster WJ et al (2005) The history of ocean resources: modeling cod biomass using historical records. Front Ecol Environ 3(2):84–90
Rozas LP, Caldwell P et al (2005) The fishery value of salt marsh restoration projects. J Coast Res SI(40):37–50
Salen-Picard C, Darnaude AM, Arlhac D, Harmelin-Vivien ML (2002) Fluctuations of marcobenthic populations: a link between climate-driven river run-off and sole fishery yields in the Gulf of Lions. Oecologia 133:380–388
Sanchez-Gil P, Yañez-Arancibia A (1997) Grupos ecologicos funcionales y recursos pesqueros trpicales. In: Flores D, Sanchez-Gil P, Seijo JC, Arreguin F (eds) Anañlisis y Diagnostico de los Recursos Pesqueros Criticos del Golfo de Mexico. EPOMEX Serie Cientifica, Universidad A. de Campeche, 496 pp. pp 357–389
Shaffer GP, Day JW, Mack S, Kemp GP, Heerden I van, Poirrier MA, Westphal KA, FitzGerald D, Milanes A, Morris CA, Bea R, Penland PS (2009a) The MRGO navigation project: a massive human-induced environmental, economic, and storm disaster. J Coastal Res 54:206–224
Shaffer GP, Wood WB, Hoeppner SS, Perkins TE, Zoller JA, Kandalepas D (2009b) Degradation of baldcypress-water tupelo swamp to marsh and open water in Southeastern Louisiana, U S A: an irreversible trajectory? J Coastal Res 54:152–165
Sheridan P, Hayes C (2003) Are mangroves nursery habitat for transient fishes and decapods? Wetlands 23:449–458
Vermeer M, Rahmstorf S (2009) Global sea level linked to global temperature. PNAS 106:21527–21532
Vidal-Hernandez L, Pauly D (2004) Integration of subsystem models as a tool toward describing feeding interactions and fisheries impacts in a large marine ecosystem, the Gulf of Mexico. Ocean Coast Manage 47:709–725
Yañez-Arancibia A, Lara-Dominguez AL, Sanchez-Gil P, Day JW 2004. Interacciones ecologicas estuario-mar: marco conceptual para el manejo ambiental costero [Estuary-sea ecological interactions: conceptual frame for coastal environmental management]. In Diagnostico Ambiental del Golfo de Mexico [Environmental Diagnosis of the Gulf of Mexico]. INE-SEMARNAT, Mexico. DF, 280 pp
Wilson JG (2002) Productivity, fisheries and aquaculture in temperate estuaries. Estuarine Coastal Shelf Sci 55:953–967
Zimmerman RJ, Minello T (1984) Densities of *Penaeus aztecus, Penaeus setiferus*, and other natant macrofauna in a Texas salt marsh. Estuaries 7:421–433
Zimmerman R, Minello T, Klima E (1989) Problems associated with determining effects of nursery habitat loss on offshore fishery production. Am Fishery Soc Newslett, Early Life History Section 10(3)
Zimmerman RJ, Minello TJ, Klima EF, Nance JM (1991) Effects of accelerated sea-level rise on coastal secondary production. In: Bolton HS (ed) Coastal wetlands. American Society of Civil Engineers, New York, pp 110–124