

Alterations to Estuarine and Marine Habitat Quality and Fish and Invertebrate Resources: What Have We Wrought and Where Do We Go?

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ABSTRACT

Some coastal habitat types have been established as nursery grounds for estuarine and marine nekton, presumably because these habitats are the template on which population and community dynamics occur. However, the linkage between structured coastal habitat and nekton production is being altered by development; thus, we are studying this linkage while it is changing. Modification to coastal landscapes can have direct and indirect consequences that may lead to reduced or eliminated access to favorable nursery habitat, which is predicted to reduce growth, increase mortality, and/or modify settlement patterns. Cumulative impacts are more problematic because they are not immediately noted and build up over time to produce a more substantial impact to habitat. On a small scale, bulkheads, rip-rap, and levees eliminate or significantly reduce access to intertidal aquatic habitat, but these can accumulate across the landscape and fragment and reduce available habitat. However, the proliferation of patchiness (non-continuous habitat segments) has received little attention in coastal environments but has been hypothesized to contribute to reduced environmental sustainability. Herein, we review the literature on habitat alteration in nearshore aquatic environments and provide a time line on the assessment of these alterations. Particular focus needs to be placed on assessing the ecological value of habitat that has undergone alteration versus that which is still natural or has recently undergone restoration in order to evaluate and predict habitat resilience and sustainability. Managers and policy makers must include cumulative impacts in their short- and long-term coastal management plans.

KEY WORDS: Impact, landscape, linkage, resources

Las Modificaciones a la Calidad del Hábitat Estuario y Marina y a los Recursos de Pesca y Invertebrado: ¿Qué Tenemos Forjado y Dónde Vamos Nosotros?

Algunos tipos del hábitat costeros han sido establecidos como motivo de guardería infantil para los organismos del estuario y del mar, presumiblemente porque estos hábitats son la plantilla en cuál ocurre dinámicas de población y comunidad. Sin embargo, la conexión entre la producción costera en los hábitats estructurados y los organismos es alterada por el desarrollo; así, estudiamos esta conexión mientras cambia. La modificación a paisajes costeros puede tener las consecuencias directas e indirectas que pueden reducir o eliminar el acceso al hábitat favorable. Esta modificación es predicho reducir el crecimiento, aumentar la mortalidad, y/o modificar las patrones establecerse. Los impactos cumulativos son más problemáticos, porque ellos no son notados inmediatamente y construyen con el tiempo para producir un impacto más substancial al hábitat. A pequeña escala, los mamparos, el rasgón-golpecito, y los diques eliminan o reducen apreciablemente acceso al hábitat acuático entre las mareas, pero éstos pueden acumular a través del paisaje con el resultado de fragmentar y reducir el hábitat disponible. Sin embargo, la proliferación del hábitat no-continuo divide ha recibido atención mínima en ambientes costeros, pero una hipótesis ha sido formado para contribuirlo a la sostenibilidad ambiental reducida. En esto, nosotros revisamos la literatura en la modificación del hábitat en los ambientes acuáticos cerca de la costa y proveemos una línea de tiempo en la evaluación de estas modificaciones. Necesitamos enfocar en particular sobre la evaluación del valor ecológico del hábitat modificado contra el que es todavía natural o ha experimentado recientemente la restauración para evaluar y predecir la elasticidad y la sostenibilidad del hábitat. Los directores y las políticas deben incluir los impactos cumulativos en sus planes costeros de manejo.

PALABRAS CLAVES: Impactos, paisaje, conexión, recursos

L'altération de la Qualité des Habitats D'estuaires et Marins et les Ressources en Invertébrés et Poissons: Qu'avons nous Réalisé et ou Allons Nous?

Quelques types d'habitats côtiers ont été définis comme étant des « nurseries » pour le necton d'estuaire ou de mer, probablement parce que ces habitats constituent le modèle où se réalise la dynamique de populations et des communautés. Cependant, la relation entre l'habitat côtier structuré et la production de necton est altérée par le développement ; aussi, nous étudions cette relation pendant son changement. Les modifications du paysage côtier peuvent avoir des impacts directs ou indirects, qui peuvent réduire ou supprimer l'accès à des « nurseries », ce qui présage une réduction de la croissance, une mortalité accrue et (ou) une modification des modèles d'installation des juvéniles. Les impacts cumulés sont plus problématiques car il ne sont pas immédiatement observés et agissent à long terme pour produire un impact plus profond sur l'habitat. Sur une petite échelle, digues, enrochements et jetées éliminent ou réduisent considérablement l'accès aux habitats intertidaux, mais ces effets peuvent s'accumuler sur la côte et fragmenter et réduire les habitats disponibles. Cependant, la prolifération de la fragmentation de l'habitat (en segments discontinus) a été peu étudiée en environnement côtier, mais a fait l'objet d'hypothèses quant à sa contribution à réduire la durabilité de l'environnement. Dans le présent travail, nous avons revu la littérature disponible sur la dégradation des habitats marins côtiers et proposé un guide pour l'étude de ces altérations. Une attention particulière doit être portée sur l'évaluation écologique des habitats qui ont subi des altérations, par rapport à d'autres en état naturel ou qui ont bénéficié de restaurations, dans le but d'évaluer et de prédire la résilience et la durabilité de ces habitats. Les gestionnaires et les décideurs doivent prendre en compte l'action des impacts cumulés dans leurs plans, à court et long terme, de gestion de l'environnement.

MOTS CLÉS: Impact, paysage, paysage, relations, échelle

INTRODUCTION

Estuarine-dependent fishes and decapods (nekton) have complex life histories exemplified by spawning offshore (or nearshore), larval recruitment into estuaries and settlement into nursery habitat where they grow to late juvenile or adult stages before migration of adults back offshore to spawn (Beck *et al.* 2001, Minello *et al.* 2003, Roundtree and Able 2007). Thus, the integrity of these coupled coastal landscape features is vital for sustained fishery production. Within this holistic view success is directly linked to habitat diversity, quality, and quantity nested within a framework of abiotic variability, landform diversity, and physical processes (Simenstad *et al.* 2000, Peterson 2003, Peterson *et al.* 2007, Hood 2007). Keeping these complex and productive nearshore environments intact under continued developmental pressure is vital to local and regional ecologic and economic sustainability because healthy coastal ecosystems are a productive commodity, providing both direct and indirect services to society such as food production, nutrient cycling, erosion control, waste treatment, storm protection, and recreational and cultural use. In concert with changes in land usage, humans have also degraded coastal habitat throughout the world and this is correlated with movement of humans to coastal areas with subsequent development pressures. For example, fifty-three percent of the U.S.'s population lived in coastal counties in 2003, and that number is projected to increase more than 4% by 2008 (Crossett *et al.* 2004). As a result, coastal ecosystems worldwide are under increasing pressure from human activities and associated development (Jackson *et al.* 2001, Reed *et al.* 2006, Constanza *et al.* 2008), and numerous coastal habitats have been degraded to various extents (Kennish 2001, Holland *et al.* 2004, Orth *et al.* 2006, Van Dolah *et al.* 2008, Partyka and Peterson 2008) at a number of spatial scales.

In recent decades, there has been a considerable national and international focus on regional- or large-scale impacts to fisheries sustainability by fishing activity directly through gear impacts (Skilleter *et al.* 2006, Bearzi *et al.* 2006) or indirectly via impacts on food webs (Coleman *et al.* 2004, Pauly 2007), bycatch (Diamond 2005), eutrophication and hypoxia (Livingston 2007), sewage outfalls (Guidetti *et al.* 2002); global climate change (Roessig *et al.* 2004, Craft *et al.* 2009), impounding habitat (Brockmeyer *et al.* 1997, Sheaves *et al.* 2007), and storms, hurricanes and sea-level rise (Emanuel 2005, Webster *et al.* 2005). However, there are other impacts that are often not considered at these scales like invasive species, reduced freshwater input to estuaries, modified tidal circulation, and agriculture, domestic and industrial wastes (Nichols 1986, Ritter *et al.* 2008), impaired water quality and pollution in estuaries from marina's (McAllister *et al.* 1996), port and harbor development (Vandermeulen 1996), numerous dredge and fill operations (Johnston 1981), and actual burial of vital habitat due to

beach renourishment (Lindeman and Snyder 1998).

In contrast to these more visible impacts to habitat, are small-scale, cryptic changes that have been termed cumulative impacts (Odum 1982, Burns 1991, Johnston 1994). Though they are small in nature, their impacts can sum up to more regional-scale impacts and can lead to fragmentation at larger coastal landscapes (Layman *et al.* 2004, Toft *et al.* 2007, Valentine-Rose *et al.* 2007, Elmore and Kaushal 2008, Partyka and Peterson 2008). Although scientists expressed concern about multiple, small-scale modifications and subsequent cumulative impacts to habitat in coastal ecosystems early (Hutton *et al.* 1956, Allen 1964, Arnold 1964, Hedgepeth 1966, Mock 1967, Taylor and Saloman 1968, Odum 1970, Sykes 1971), the public perception and resource management agencies have been slow to change. For example, management agencies have yet to directly incorporate this insidious problem into their short- and long-term management goals and their permitting practices have been inconsistent. In order to effectively deal with habitat modifications and their cumulative impacts to coastal ecosystems we must "think globally act locally" (Burns 1991).

These impact scenarios as they directly impact humans and property have driven an outcry from sociologists, conservationist, and anthropologists alike to develop a better understanding of the social-ecological tradeoffs in coastal zone management mainly when faced with natural disasters (Balmford and Bond 2005, Adger *et al.* 2005, Austin 2006). This emerging discipline in an ever human-dominated planet focuses on policy associated with coastal development activities and requires equal input of science-based management, economic tradeoffs, and cultural/societal benefits in order to effectively produce sustainable ecosystems via 'smart growth' scenarios in the face of increasing sprawl while reducing the impacts to human health. This is particularly important where coastal ecosystems are nestled within human-dominated landscapes must be managed sustainability within a complex background of natural (hurricanes, storms) and anthropogenically-escalated climate change (sea level rise, flooding, larger and greater frequency of storms) (Emanuel 2005, Webster *et al.* 2005, Adger *et al.* 2005). Climate change influences primary and secondary production and management must include this global variation along with fishing effects to better reflect reality (Benson and Trites 2002). Evaluating environmental and anthropogenic impacts to nature can be complex but it is clear that habitat loss or degradation are central themes in the reduction of important ecological services (Balmford *et al.* 2002, Adger *et al.* 2005, Balmford and Bond 2005, Constanza *et al.* 2008). In fact, much of what we know about reduced biodiversity is linked to patterns of habitat alteration or loss (Peterson *et al.* 2000, Balmford and Bond 2005, Partyka and Peterson 2008), particularly if that habitat type is considered a foundation species (Bracken *et al.* 2007). However, little data are available on the influence of changes in habitat condition or

extent on important ecological services (Balmford and Bond 2005).

REVIEW GOALS

Defining the threshold among different scales at which any impact operates is problematic because it is difficult to quantify small- and regional-scale events as both depend on the overall scale of the system under study. Additionally, local-scale phenomena can translate into regional-scale and potentially large-scale problems as they accumulate within a system. Thus, we follow the Turner (1990) and Kennish (2001) approach (Table 1) as being more descriptive and less quantitative in defining the scale of impact recognizing the argument above. Finally, although some argue that the loss of a particular habitat type is simply change to a different habitat type and thus we have not lost habitat, not all habitat types are the same in terms of productivity, and all do not provide the same level of ecological services and thus function in a complex estuarine/marine ecosystem (Beck *et al.* 2001, Stoner 2003, Peterson 2003, Minello *et al.* 2003, Brody *et al.* 2008).

The general goal of this review is to acknowledge the discussion on global- and large/regional-scale anthropogenic impacts to estuarine/marine ecosystems that are in the public's view and, more importantly, to focus our efforts on these small-scale impacts that build into regional scale impacts and to elucidate the fact that these local changes are typically addressed as "business as usual" and that these insidious alterations are not usually incorporated into local, state and federal management plans or policies. Herein we (1) review papers on a temporal scale on salt marsh, seagrass, mangrove, and coral reef habitat types and an overall view of all impacts, and then (2) provide examples of studies on vital intertidal and subtidal nursery grounds excluding coral reef habitats to illustrate loss or degradation and subsequent modification of habitat and reduction of nekton resources important to coastal productivity and sustainability.

APPROACH

Table 1. Examples of three scale-dependent levels of anthropogenic and natural impacts to coastal habitat.

Type	Example
Local (direct)	diking, bulkheading, culverts, tide gates, dredging, rip-rap, ditching, canals, levees, pipelines, salt hay farming, boat wakes/waves, filling, and impound-
Regional or large (direct or indirect)	coastal subsidence caused by subsurface water, gas, oil withdrawal, reduced sediment inputs and accretion, dams and weirs, and changed hydrology
Global	global climate change, sea level rise, erratic weather (hurricane/ storms) patterns, and regime shifts

Estuarine and marine landscapes are viewed as being hierarchical in nature and habitat is linked at various scales but all are set within an abiotic framework based on an organisms physiological capabilities and that habitat loss or degradation is fragmenting these linked landscapes (Stoner 2003, Peterson 2003, Pittman *et al.* 2004, Halpern *et al.* 2008). These studies illustrate the importance of keeping these coastal environments intact in order to maintain a productive and sustainable coastal ecosystem.

For this review, papers were extracted from the authors personal library, internet searches on Google Scholar, and internet databases like Environmental Complete (1947-12 June 2008), Biological Abstracts (1969 -12 June 2008), Aquatic Sciences and Fisheries Abstracts (1974 -12 June 2008), and Web of Science (1975 - 24 June 2008). These were used to locate references of interest but our larger searches were conducted using the Web of Science with the following keywords: marine, coastal, aquatic, coupled with habitat, environment, coupled with loss, degradation, alteration and decrease. These were done for all habitat types and seagrass, mangrove, saltmarsh, and coral reef habitat separately. We also searched the Web of Science using bulkhead, roads, levees, and rip rap by year to better evaluate previous research on small-scale impacts.

GENERAL FINDINGS

There is a global loss or deterioration of coastal habitat types due to increasing anthropogenic pressures from increases in coastal populations and associated activities (Crossett *et al.* 2004, Pendleton 2008). In our survey, a total of 7,142 citations were obtained from the Web of Science (1975 - 24 June 2008; Figure 1) search using the keywords noted above for all habitat types pooled and then separately for coral reef (n = 242), salt marsh (n = 185), seagrass (n = 165), and mangrove habitat types (n = 117).

Additionally, a reduced search with keywords that focused on small-scale alterations produced only 62 citations over the same time period. Either pooled across all habitat types or individually, the number of citations has increased starting in the 1990s through 2007, with coral reefs being the most cited habitat type followed by salt marsh, seagrass and mangrove in total numbers. This numerical order generally follows that of Duarte *et al.* (2008) in their larger search except for seagrass which ranked third of four in our truncated search compared to fourth of four in Duarte *et al.* (2008).

Fragmentation of estuarine landscapes has typically been related to actual coastal land changes (e.g., forest to impervious surfaces) adjacent to estuarine ecosystems (Thomas 1995, Lotze *et al.* 2006), other less obvious alterations at many scales also fragment estuarine landscapes. Cumulative impacts, local small-scale habitat alterations accumulate and coalesce into regional- and large-scale impacts, can influence or reduce the function of the estuarine landscape and thus sustainability. For example, small, cryptic impacts like boat scarring of

seagrass (Burfiend and Stunz 2007), bulkheading of intertidal saltmarsh (Douglass and Pickel 1999; Peterson *et al.* 2000; Hendon *et al.* 2000), dock shading (Sanger *et al.* 2004), levee building (Reed *et al.* 2006), and commercial and municipal piers development (Able *et al.* 1999, Duffy-Anderson and Able 1999), can lead to larger fragmented tracks of altered and hardened shorelines (Toft *et al.* 2007, Brody *et al.* 2008, Peterson and Partyka 2008). This fragmentation may influence species-specific recruitment success (Eggleston *et al.* 1998), fish assemblage structure and diversity (Layman *et al.* 2004, Partyka and Peterson 2008), modified hydrology and increased flooding in coastal regions (Brody *et al.* 2008), and ultimately secondary production in estuarine and marine ecosystems (Valentine-Rose *et al.* 2007). All of these can, over time, reduce estuarine and marine productivity and sustainability through cumulative impacts.

CONCLUSIONS

Societal mind-sets about development and its subsequent environmental and human-health consequences in the short- and long-term must be linked to the known relationship between habitat quality and quantity as both influence survival, growth and sustainability of nekton and habitat alteration in nursery areas can severely impact survival and recruitment success (Gibson 1994). Furthermore, nursery habitat quantity is probably the most important component of the environment as it is the template for past, current, and foreseeable future of sustainable populations and habitat fragmentation can influence these future populations over the long-term. Suchanek (1994) noted in his review that "... the most critical part of maintaining biodiversity is maintaining the dynamic set of interactions that define what that ecosystem is and how it functions." Valiela *et al.* (2004) argued that "the reason we have lost wetland habitat is that we have repeatedly made the economic decision that other land covers are more profitable and desirable." They suggest we must "...redouble our efforts to help the public and political sectors better reconcile the balance between economic imperatives and the less-apparent benefits provided by coastal wetlands" in order to reach a balance between development and nature's sustainability.

Interestingly, as natural and human-induced environmental alterations continue to occur, society has realized earlier alterations may have created present-day problems. For example, Rounsefell (1964) and Allen (1964) documented the construction of the 76 mile long Mississippi River-Gulf Outlet (MR-GO) canal starting in the late 1950s and its immediate direct impact to adjacent salt marsh habitat but also noted indirect impacts like the volume of mud removed creating spoil banks and spoil impoundments that influenced normal water flow through the marshland. Additionally, the canal introduced a salt wedge into Lake Pontchartrain increasing its salinity and organisms associated with higher salinity environments. It has recently been debated that the MR-GO was partially responsible for the flooding and levee breach in New Orleans following Hurricane Katrina as Turner (2006) quantified peaks in sediment deposition just after the storm where navigation channels like the MR-GO confined and focused the incoming storm surge. There is considerable local, regional and national debate and possible movement to fill in the canal to reduce subsequent hurricane impacts and wetland loss (Hallowell 2005, Bourne 2007) and the U.S. Army Corp of Engineers has developed such a plan (USACE 2008) at great cost.

In conclusion, over the last five decades there have been calls for action to stop or reduce these small-, regional- and large-scale projects because of the perceived negative impact to mangroves, seagrass, salt marsh, and estuarine productivity in general (Hutton *et al.* 1956, Allen 1964, Arnold 1964, Hedgpeth 1966, Odum 1970, 1982). These small-scale impacts continue today and the rate of impact appears

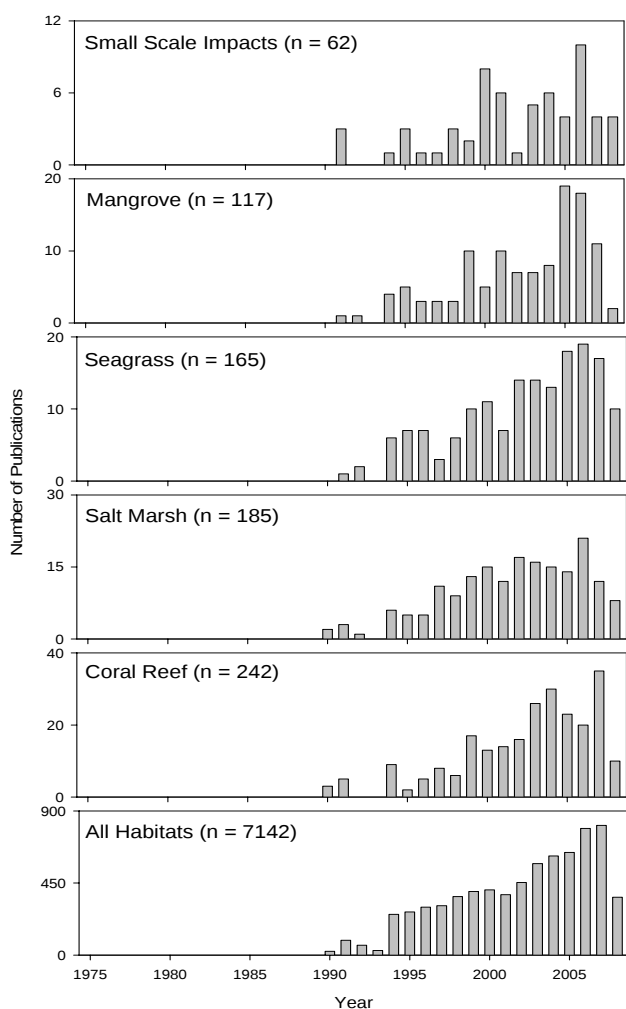


Figure 1. Plot of the number of publications from the Web of Science database for all habitat types and for the four individual habitat types plus all habitat types using only the reduced set of key words noted in the text. The search ended 24 June 2008 and thus is incomplete for that year.

greater given the pattern of humans moving to the coastline in great abundance (Crossett *et al.* 2004, Pendleton 2008). In fact, in their review of wetland 404 permitting in Texas and Florida, Brody *et al.* (2008) determined:

- i) There is more intense and widespread wetland alteration than previously reported,
- ii) Urban sprawl is increasing primarily from residential developments in coastal areas, and
- iii) A large percentage of wetland alteration permits in both states were issued in 100-year floodplain areas modifying the natural hydrology and creating or enhancing flooding.

Their results illustrate the importance of tracking wetland alteration on a site-by-site (local) basis but also at regional- and large-scales (spatial and temporal) as these are the scales at which decision makers operate and at the scale these cumulative impacts can be viewed in terms of wetland loss and subsequent impacts to sustainability. These modifications to coastal habitat types in a world of climate change and its slower modifications like surface elevation relative to sea level rise and subsidence and increased water temperature impact coastal aquatic systems and coastal sustainability. An understanding of these is vital to land-use planners, decision makers, state and federal managers, legislators, and the public and these cumulative impacts should be incorporated into management plans on all levels of society.

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