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Fishery Habitat in Estuaries of the Gulf of Mexico: Reflections on Geographical Variability in Salt Marsh Value and Function

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GULF AND CARIBBEAN

RESEARCH

FISHERY HABITAT IN ESTUARIES OF THE GULF OF MEXICO: REFLECTIONS ON GEOGRAPHICAL VARIABILITY IN SALT MARSH VALUE AND FUNCTION

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ABSTRACT: After 35 years working with many estuarine ecologists, I have concluded that all salt marshes are not created equal. This may seem like a trivial conclusion, but not everyone is a believer. While coastal salt marshes have many important ecological functions, their ability to support marine fisheries appears dependent on some specific characteristics. Extensive flooding of the marsh surface and a large amount of edge per area of vegetation have been identified as important in supporting production of juvenile brown shrimp (*Farfantepenaeus aztecus*), white shrimp (*Litopenaeus setiferus*), and blue crab (*Callinectes sapidus*). Data on other species are limited, but these same qualities also may support production of Red Drum (*Sciaenops ocellatus*) and Spotted Seatrout (*Cynoscion nebulosus*). These characteristics are common in the salt marshes of the northwestern Gulf of Mexico and are partly responsible for the high fishery production in the region. Wetland loss in this region also is extensive and related to wetland value, and success in creating new salt marshes that support fisheries will depend on establishing these same characteristics of edge and elevation that make the natural marshes valuable.

KEY WORDS: Penaeid shrimp, wetland loss, essential fish habitat, salt marsh production, marsh restoration

HOW SCIENCE HAS CHANGED

I was asked to reminisce in this article on how science has changed since I was in graduate school. Just being asked this question is annoying because it means that they think you are old. And because you actually are old, it is difficult to clearly remember what life was like as a graduate student at Texas A&M in 1972. It's not so much that science has changed over these years, but there has been a dramatic change in the delivery of scientific products. What I do remember is IBM Selectric typewriters, LEROY lettering systems, rapidographs, and press—on letters.

Before word processing software was in common use, manuscripts were typed by students, scientists, or a secretary often on an IBM Selectric. This typewriter was a major improvement over older models because it had a round ball with letters and numbers on it that replaced the conventional basket of type bars. The Selectric ball moved across the page eliminating the carriage return, and the ball could be replaced to use different fonts. When working properly, it also allowed you to erase mistakes, a common occurrence for novice novelists. I got halfway decent at typing with the thing, although typing still today is a two—finger operation for me. I remember hiring Margie Watson to type my dissertation in 1979, and she didn't like the Selectric because it was not fast enough for her; she could type over 100 words per minute. In the early 1980s, working as a government scientist, we had a secretarial pool that would type manuscripts. Often, each new version would have new mistakes to be corrected, and getting a final clean copy generally was exasperating. By 1986, the Selectric brand was retired as word processers and personal computers took over this task; and scientists became their own secretaries.

Graphics in publishing was the other huge advancement. Making figures for publication in the 1970s was a major operation, using protractors, graph templates behind velum, and various lettering systems. Most graphics looked crude compared to even basic Excel figures created today. Simply drawing axes on a 2—dimensional graph and labeling the units was difficult. Stick—on letters helped but were hard to get on straight. Real pros used a LEROY lettering set, where you traced a template of letters and numbers, and a remote pen placed them on paper. The ink pens used for this work were rapidographs; separate pens were needed to draw lines of different widths. These are still used by drafters and architects. All of this meant that you could spend a day making a nice bar graph or scatter plot that takes a few minutes today on your computer. And don't get me started on using a *camera lucida* to draw microscopic animals; thank heavens for digital photography.

Presentations at scientific meetings also have changed substantially from when I first presented on copepod research. We copied text and figures onto transparencies and used overhead projectors or took photographs

to make slide presentations. Before PowerPoint and digital cameras, we thought a big advancement was taking color slides from a computer monitor running a crude graphing program called Energraphics. We would go into the office at night, turn off the lights, and set up a camera on a tripod to take presentation slides.

Another major change over this period has been the ease of data analysis driven by computing power, and a related issue, the availability of more and more complicated statistical analyses. I won't talk about slide rules, since I never really got the hang of them and calculators saved me. But the arrival of personal computers made a huge difference in the way we conducted science. I doubt that few ecologists today could easily do the calculations for a t–test without a computer. A relatively simple ANO-VA for my dissertation was run with

FORTRAN and SAS on a mainframe computer using a stack of punch cards about 1 ft high. Multiple runs were required to debug the program and each one had to be submitted and waited on, so it took many days to run an analysis. By 1985–1986, desktop computers were common but not laptops. In my early years working at the National Marine Fisheries Service (NMFS) lab in Galveston, we had a project in Guayaquil, Ecuador sampling postlarval shrimp in mangrove creeks. I was supposed to be the data analyst. We flew there with my state–of–the–art Compaq portable computer; it had two 5.25" floppy drives, a 9" green monitor, and was the size of a small suitcase weighing 28 lbs. We thought that we were bringing high tech computing power to South America! Using the statistical software available at the time, I remember sorting a large da-

taset that might now take 1 second in Excel and waiting 20 minutes for the results...this was just sorting the data. Now, statistical software has become so advanced that it is easy to run an analysis quickly but difficult to sort through the many diverse analytical options available. ANOVAs, t–tests, and regressions are seldom sufficient anymore, as more sophisticated analyses are available. Thus, the statistical knowledge required for ecologists has increased substantially.

These technological advancements have made data analysis and the writing of manuscripts much easier than in the past. Now, you don't even need to know how to spell! Grammatical correction software, however, still cannot punctuate compound sentences correctly, at least from my experience with student papers. And don't get me started on the need for an Oxford comma...Google it!

The early days at NMFS –
operating under benign neglect

The NMFS Galveston Laboratory has a long history studying the biology of penaeid shrimps. When I started working there in 1981, there was little direction given with regard to research needs, except to continue work on how estuarine habitats affected shrimp production. I had my salary and a small operating budget, and it was not until much later in my career that I realized how great it was to be able to conduct research without the need to constantly search for funds or respond to administrative demands. The managers in the Southeast Fisheries Science Center (SEFSC) mostly left us alone. The other great thing about working in salt marshes was no more ocean research cruises! One of the professors at Texas A&M, Don Harper, had a poster on the wall in his office showing one of his graduate students projectile vomiting off the stern of a trawler, with a caption that read "So you want to be a marine biologist?" After dealing with seasickness on various research cruises, I concluded that my constitution was better suited for small boats in the bay.

I was interested in predator–prey interactions and began experiments using juvenile shrimp as prey. Getting fish to eat shrimp in the laboratory was not as easy as expected, but eventually we conducted a series of experiments to examine how vegetative structure, sediment type, and water turbidity affected predation rates. We also examined prey selection by various fish predators (Figure 1), shrimp behavior, and selection by shrimp for different protective habitat characteristics. At the same time, Roger Zimmerman was working on feeding of young shrimp on food sources such as polychaete worms, peracarid crustaceans, and benthic and epiphytic algae (Figure 2). Together, we tried to make the case for the value of smooth cordgrass (Spartina alterniflora) marshes in providing food and protection for young shrimp. We also began a sam-

FIGURE 1. Southern flounder (Paralichthys lethostigma), one of the primary predators on penaeid shrimp and used in laboratory predator–prey experiments.
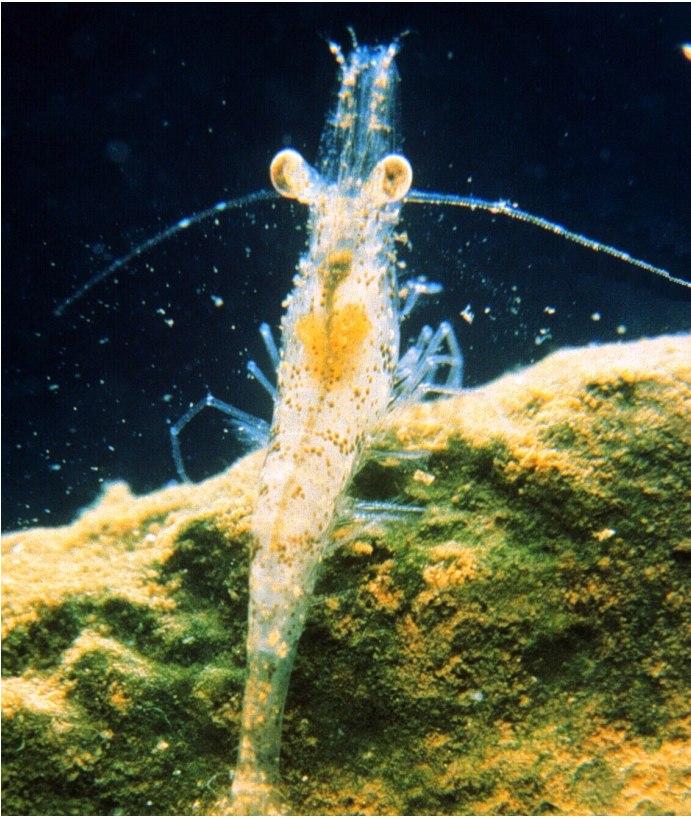
FIGURE 2. *Postlarval shrimp feeding on epiphytic algae (photograph by R. Zimmerman).*

pling program using a drop sampler (Figure 3) in Galveston Bay to study habitat selection in the field.

Designing and analyzing ecological experiments was still somewhat new to me, and one of the most influential publications at the time was Stuart Hurlbert's 1984 paper on pseudoreplication and the fundamentals of experimental design. In this paper, he made a clear distinction between laboratory and field experiments and discussed the inferences that could be made from different types of ecological studies. His discussion was very helpful in thinking about how to design many of our experiments. Hurlbert also cited demonic intrusion as a possible influencing factor in experiments, and I am sure that much of my work was thusly affected! Interestingly, he did not shy away from citing examples in the literature where experiments were poorly designed or analyzed incorrectly. Luckily, I hadn't published enough at the time to be included.

HISTORICAL PERSPECTIVE OF SALT MARSH VALUE IN ESTUARIES – BASED ON EAST COAST INFORMATION

Salt marshes have not always been considered valuable habitats for fishery species. In Chapman's 392–page treatise on 'Salt Marshes and Salt Deserts of the World' (Chapman 1960), I found no mention of fish or nekton using marshes; animal use was mainly noted to be foraging by waterfowl, grazing by cattle and goats, and swarming by mosquitos.

Much of the early work on marshes in the U.S. was conducted on Sapelo Island through the University of Georgia research facility there. It was here that John Teal (1962) proposed that salt marshes exported nutrients and detritus to the estuary as a major pathway of energy transfer that supported estuarine and coastal organisms. Haines (1979) and Nixon (1980) questioned this conclusion based on newly developed stable isotope approaches, however, stable isotope studies have not always supported the importance of *Spartina* carbon in estuarine food webs (Haines and Montague 1979, Currin et al. 1995). Detrital pathways appear important and more complex than originally envisioned (Newell 1993, Newell and Porter 2000). The importance of benthic algae from marsh surfaces also complicates the story of how productive salt marshes can support coastal fisheries (Sullivan and Moncrieff 1990, Sullivan and Currin 2000). In general, however, the focus of these studies in relation to supplying food to fishery species seldom included direct feeding on the marsh surface.

The energy provided by regular semidiurnal tides that flood tidal creeks and the marsh surface is difficult to ignore, and pulsing tides have been considered important in marsh productivity and the export of energy and nutrients (Odum 1980, Childers et al. 2000). In my mind, the dominance and magnitude of these tides in East Coast marshes dissuaded conclusions about extensive direct use of the marsh surface by nekton, other than by residents such as killifish and grass shrimp (*Palaemonetes* spp.). Geographic variability in these tidal dynamics appears to be important in allowing the direct use of the marsh surface by transient fishery species (Rozas 1995). For example, the marshes near Sapelo Island are generally flooded twice each day, with a tidal range of over 2 m, and the marsh edge is only flooded around 50% of the time (Minello et al. 2012a). Other areas of these marshes are flooded much less frequently because of the steep slope of the marsh surface, and flooding durations are reduced to < 25% of the time within a few meters of the edge (Kneib and Wagner 1994, Kneib 1997a). These dendritic marshes also have relatively little edge, and the landscape and tidal characteristics make the marshes seem terrestrial rather than aquatic. Indeed, when visiting Ron Kneib's research sites on Sapelo Island, we arrived in a pick–up truck rather than a boat.

Kneib and Stiven (1978) first published on the direct use of the marsh surface by Mummichog (*Fundulus heteroclitus*) on Sapelo Island using pit traps, and subsequently Ron Kneib followed this work by conducting numerous studies on the role of these resident fish in salt marsh ecology (Kneib 1991, Kneib and Wagner 1994, Kneib 1997a, b). It was not until he developed the flume weir that sampled 100 m², however, that he could measure densities of transient fishery species such as white shrimp (*Litopenaeus setiferus*) on the marsh surface (Kneib 1991), because densities in the Sapelo Island marsh-

FIGURE 3. *Drop sampler used to collect nekton in Gulf of Mexico salt marshes*

es were relatively low (generally < 1/m², Kneib and Wagner 1994). In an excellent review of marshes and nekton, Kneib (1997b) developed the concept of a trophic relay where resident and transient nekton transferred energy off the marsh surface through predator–prey interactions. Using the relatively low biomass estimates in Georgia *Spartina* marshes and P:B ratios gleaned from the literature, he also estimated annual secondary production for transient fishery species (including white shrimp and several fish species) to be around 9.5 kg/ha wet weight from the mesotidal marsh ecosystem.

HOW OUR WORK ON MARSHES IN THE GULF OF MEXICO FITS INTO THE EAST COAST PARADIGM

As a disclaimer, I should state that my views on marsh ecology are decidedly shrimp oriented and colored by work in the northwestern Gulf of Mexico (GOM). One reason for the paucity of information on nekton using the marsh surface is that sampling in this habitat is challenging. Until various enclosure samplers were developed, it was difficult to measure habitat use in marsh systems (Rozas and Minello 1997, Connolly 1999). In the early 1980s, we first used a drop sampler in salt marshes of Galveston Bay (Figure 3) and demonstrated that high densities of shrimp and other transient nekton were using the marsh surface (Zimmerman et al. 1984, Zimmerman and Minello 1984). Since that time, we have sampled marshes throughout the GOM and measured densities on the marsh surface that are somewhat astounding; mean penaeid

shrimp densities as high as 85.1 individuals/m² (SEM = 22.6) were reported by Mace and Rozas (2017) in saline marsh edge habitat of Sabine Lake, Texas. A large number of studies in GOM coast marshes have found similar patterns of marsh edge use (Baltz et al. 1993, Peterson and Turner 1994, Minello 1999, Rozas and Minello 2015). In comparison, relatively few attempts have been made to measure nekton use of the marsh surface along the Atlantic Coast of the U.S; and most of these have shown that marshes are not used to this same extent (see Minello et al. 2003 for a review). The degree of flooding that makes the marsh surface available for exploitation would seem to be an obvious and important factor (Rozas 1995, Minello et al. 2012a). Water levels in the microtidal systems of the northwestern GOM are dominated by meteorological events, and the marsh edge in Galveston Bay is generally flooded over 80% of the time (Minello et al. 2015).

The focus on edge in GOM marshes is important because many of these marshes are fragmented with a great amount of edge (Figure 4). Our GIS analysis in Galveston Bay showed that almost 10% of the marsh vegetation was edge habitat (i.e., within 1 m of the marsh–water interface). This edge habitat appears to be used much more intensely by penaeid shrimps (Figure 5) and blue crab (*Callinectes sapidus*) than inner marsh habitats (Minello et al. 1994, Minello and Rozas 2002), and one approach to determine the abundance of nekton in a marsh complex requires measuring small–scale density patterns combined with a landscape and microtopography
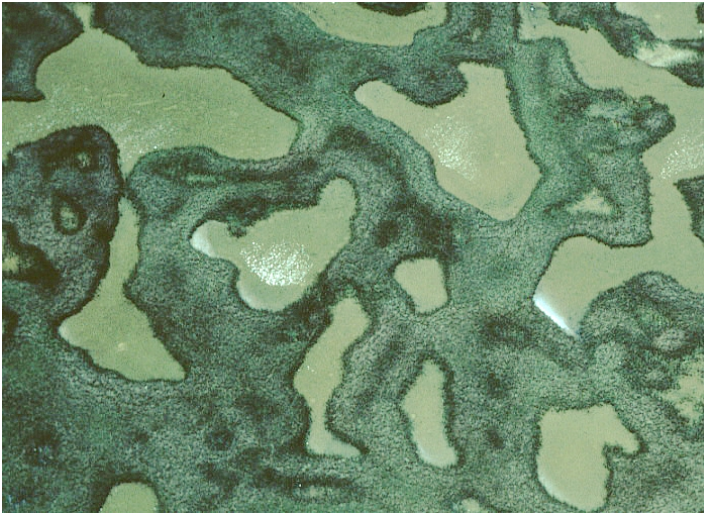
FIGURE 4. *Reticulated marsh in Galveston Bay, TX.*

analysis (e.g., Rozas et al. 1988; Rozas and Reed 1993; Ennis and Peterson 2015) to estimate the use and amount of marsh edge. Using such an approach, we estimated population sizes and annual production of penaeid shrimps and blue crab in Galveston Bay marshes (Minello and Rozas 2002, Minello et al. 2008). For penaeid shrimp alone, annual production was 237 kg/ha of wet weight from the marsh complex, about 25x higher than the estimates by Kneib on Sapelo Island (Minello et al. 2008). Various other modeling approaches have estimated similarly high production of shrimp from GOM marshes (Haas et al. 2004, Leo et al. 2016).

As an aside, I miss reading many older scientific publications, because the writing was often entertaining and occasionally even humorous (see Hutchinson 1959, Deevey 1960, Hardin 1960). I assumed that once biologists had reached some level of competence and had a decent reputation in their field that they could get by with a quip or semi–humorous sentence. I tried to insert one sentence about shrimp 'literally and figuratively living on the edge' in a manuscript about shrimp living on the marsh edge (Minello and Rozas 2002).

FIGURE 5. *Handful of shrimp from highly productive Galveston Bay marshes.*

This analogy was an attempt to highlight the edge hypothesis and remind the reader of the consequences of wetland loss in a way that would be memorable. Perhaps indicative of my scientific status, the sentence was rejected by one reviewer as being "too cute." My conclusion is that reviewers don't seem to be able to take a joke anymore, even a small one.

Wetland loss is a major concern in coastal marshes of Louisiana and throughout the northern GOM. This loss is caused by high rates of relative sea level rise and channelization of wetlands (Turner 1997, Day et al. 2000). If wetlands are important in supporting shrimp populations (Turner 1977, 1992), why don't we see population declines coinciding with this wetland loss? There is some evidence that wetland loss caused by submergence and degradation of marshes temporarily increases the amount of marsh fragmentation and edge (Browder et al. 1985, Chesney et al. 2000). Along with salt water intrusion, this fragmentation of degrading marshes may explain the current lack of a wetland signal in shrimp populations (Zimmerman et al. 2000). The overall amount of marsh edge in these systems does not appear to be declining yet (Minello et al. 2017), but continuing marsh loss will inevitably reduce edge habitat and likely population sizes of shrimp (Figure 6).
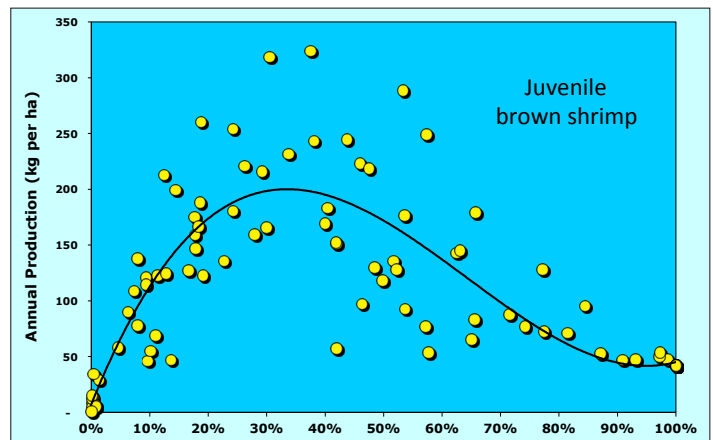

FIGURE 6. *A hypothetical relationship between juvenile brown shrimp (Farfantepenaeus aztecus) production and marsh loss (as percent water in marsh) in Galveston Bay (data from Minello et al. 2008).*

Essential Fish Habitat and the nursery role concept

In 1996, Congress included language on essential fish habitat (EFH) in reauthorizing the Magnuson–Stevens Act. EFH was to be identified for all managed fishery species and was defined as "...those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." Despite the nebulous wording, we thought that the type of ecological work we had been conducting for 15 years was finally being legitimized by the National Marine Fisheries Service (NMFS) and a flood of research support would begin. We worked with NMFS staff in Silver Spring, MD to operationalize the concept of EFH. Surprisingly to us, there was some opposition to the concept by agency fishery biologists, because they felt

that all habitats were essential. This view seemed to ignore the point of the designation which was to identify habitats that were likely more important than others in supporting particular fishery species. It seemed obvious that we should identify and protect those habitats, particularly for species already threatened by overexploitation, and this EFH approach was one way to identify important habitats. One problem, however, is that the legislation specifically requires a line to be drawn between essential and nonessential habitat. This distinction makes little sense to me. I believe that we should simply try to rank habitats with regard to their essentialness, and no habitat type would need to be labeled as nonessential.

Ecologists and fishery biologists from throughout the agency developed an initial approach to identify EFH that involved different levels of available information: 1) presence—absence data to identify a species' range; 2) density or abundance data in different habitats, 3) habitat—specific growth and mortality information, and 4) habitat—related production estimates. Decisions on habitat value should be based on the data available with information on habitat—related vital rates and production considered the gold standard for determining EFH. By combining such information on use with how rare a habitat is and whether a habitat is threatened, I conducted an exercise to rank estuarine habitats for juvenile brown shrimp (*Farfantepenaeus aztecus*), and the rankings from highest to lowest were: seagrass, intertidal salt marsh, irregularly flooded marsh, oyster reef, and sand/mud bottom. Levin and Stunz (2005), however, pointed out that habitat importance will vary by life stage, and we used a similar modeling approach to identify EFH for white shrimp (Baker et al. 2014). While the challenge of identifying important habitats should have expanded ecological research in NMFS, most of the funds designated towards EFH were used to increase staff needed to conduct consultations, a requirement of the law. This is another example of unintended consequences or perhaps just the way our government works.

Following publication of a paper on EFH in estuaries of Texas and Louisiana (Minello 1999), I was asked to join a group of scientists organized by Mike Beck and Ken Heck to synthesize information on wetland nurseries. These projects supported by the National Center for Ecological Analysis and Synthesis are a wonderful way to get some consensus on such issues, and if you can't reach agreement, at least the meetings are in Santa Barbara, CA. We had a great time arguing about the definition of a nursery, and much of the work occurred over beers at the Santa Barbara Brewing Company. The primary product from this effort was a highly—cited paper in BioScience (Beck et al. 2001) outlining an approach for identifying nurseries that was quite similar to the EFH guidelines developed for NMFS. With a focus on comparing and protecting a similar area of habitat, the definition of a nursery did not emphasize the importance of the overall habitat area in supporting production, but Dahlgren et al. (2006) later

made that distinction. Despite the many papers pointing out that the issue is more complicated (Krause and Secor 2005, Levin and Stunz 2005, Mangel et al. 2006, Baker et al. 2014, Sheaves et al. 2015), these relatively simple approaches to defining EFH and estuarine nurseries have provided a valuable path forward for connecting habitats and fishery species.

CREATED SALT MARSHES – IT IS DIFFICULT TO BUILD FUNCTIONAL MARSHES WITHOUT KNOWING HOW NATURAL MARSHES FUNCTION

How can you build a functioning salt marsh without a good understanding of how natural marshes function? This simple concept seems to be lost on many working on habitat restoration. The common mantra of "we will only fund shovel—ready projects" and the idea that restoration projects should not involve research are particularly short sighted. Unless we understand what characteristics of natural marshes are important for the ecological functions of this habitat, it seems inefficient and foolish to build new marshes that may not have these characteristics.

Marsh restoration efforts often seem to have an objective of simply restoring marsh vegetation, but projects to restore damages to fishery production should have a primary objective of creating a marsh that provides better fishery habitat than what was there before restoration. This goal requires information on the value of the present habitat being replaced and the value of the created habitat. All of the research discussed in the previous sections is required to address these issues. Some of the obvious problems include: 1) assuming that open water has little value for fishery species, 2) assessing value for nekton by sampling abundance in only a subset of the habitat (e.g., in water adjacent to marsh vegetation because it is easier), 3) sampling at an incorrect or insufficient temporal or spatial scale, and 4) not considering vital rates and habitat—based production.

Most recently, marsh restoration efforts in the GOM have been focused on restoring fishery habitat damaged by the Deepwater Horizon oil spill. Developmental trajectories for created salt marshes have been built for the restoration of fishery production. The paucity of data available to support this effort was apparently surprising to many working on restoration plans. One of the first questions that needed to be answered was how the marshes would be built, because construction methods can affect function. Most of the salt marshes being built in the GOM are on some type of dredged material with relatively high organic content. The temporal development of these marshes should not be compared with Atlantic coast marshes built on graded—down uplands or sandy dredged material that has low organic content. The development of sediment organic matter and benthic infauna in such marshes can be quite slow; estimates for these characteristics to reach natural marsh conditions can be as high as 15—25 years (Moy and Levin 1991, Sacco et al. 1994,

Craft et al. 1999). A positive aspect of graded—down marshes, however, is that they are not displacing other aquatic habitat with fishery value.

Salt marshes built in the GOM are often constructed by planting sprigs of S. *alterniflora* on some type of dredged material, and marshes develop within a few years if the site is protected from wave erosion. After several early studies comparing nekton densities in edge vegetation of natural and created marshes (Minello and Zimmerman 1992, Minello and Webb 1997, Minello 2000), we concluded that differences in abundance at this spatial scale were relatively small if S. *alterniflora* was established and the proper elevation of the marsh was achieved. Many of the salt marshes created in this manner, however, ended up structured like football fields with no drainage or creek systems. This was a landscape scale problem. We identified a dredged material marsh with little edge and together with the U.S. Army Corps of Engineers added experimental channels that were shown to increase use of the marsh surface by nekton, including juvenile fishery species (Minello et al. 1994). We also continued to examine the value of edge in natural marshes for nekton (Minello 1999, Minello and Rozas 2002) and for benthic infauna used as food by fishery species (Whaley and Minello 2002). These studies instigated cooperative work with Kenny Rose and his students to develop several individual—based models designed to look at how marsh edge and inundation affected brown shrimp production (Haas et al. 2004, Roth et al. 2008). All of this research evidence was influential in promoting the addition of marsh edge in mitigation and restoration efforts in Texas.

Various construction techniques have been attempted to economically build marshes with more edge. These techniques include terracing, the use of ditch witches in solid marshes, and the creation of marsh islands with earth moving equipment or with small dredges. The techniques vary in construction costs and the ability to create marsh edge, and we compared construction costs with the fishery value of these marshes in Galveston Bay (Rozas et al. 2005). For some created marshes, the construction cost can be recovered by the value of excess shrimp production in about 20 years (Minello et al. 2012b).

The transfer of marsh restoration techniques to other marsh systems is challenging, however, because marshes function differently in other estuaries, and restoration objectives vary as well. For example, the high rates of relative sea level rise in coastal Louisiana will likely cause created marshes to degrade and develop edge over time. Created marshes in these systems are needed to build land and provide shoreline protection, and restoration planners are not very concerned about adding marsh edge during construction. In addition to fishery production and shoreline protection, other potential ecosystem services from marshes include: 1) providing resident nekton or bird habitat, 2) maintaining biodiversity, 3) reducing wave and storm surge damage, 4) sequestration of carbon, 5) improving water quality (usually nutrient transformation, pollutant or contaminant reduction, suspended sediment reduction), or 6) simply supplying organic matter to an estuary. Objectives should be clearly identified in restoration projects, because approaches to marsh construction can affect the ecosystem services provided.

MODELING AND THE STRUGGLE TO GET ECOLOGY INTO SHRIMP STOCK ASSESSMENTS

When I first started conducting ecological experiments on shrimp in the early 1980s, Dick Berry was the SEFSC Director, and he would often visit Galveston. We would give him presentations on our experiments and field studies revealing new insights into the ecology of juvenile shrimp, and then he would say "So what?" At the time, this comment and attitude was deflating, but the 'so what' in NMFS is related to how ecology affects fishery production and how it can be useful in developing stock assessments and managing a fishery. In 2010, NMFS supported the development of a Habitat Assessment Improvement Plan (Yoklavich et al. 2010), and one objective was to answer that question. This plan is the closest that the agency has gotten to defining an approach to conduct needed habitat science and ecological research to refine EFH designations, insert ecological interactions into stock assessments, and make progress towards ecosystem—based fishery management. The effort requires merging stock assessment models with ecological models that describe relationships between habitats and fishery production. Support for the needed research has been slowly emerging, but the need is recognized, and hopefully future management will embrace and support this plan.

FINAL THOUGHTS

Salt marshes provide a wide variety of functions, and many of these such as shoreline protection and habitat for resident species may be similar among different marsh systems. With regard to fisheries, however, marshes are not all the same, and they don't all provide the same benefits for nekton or juvenile fishery species. A better understanding of the characteristics that make marshes valuable for fisheries would be helpful in both protecting certain marshes and in creating new ones. The combination of large amounts of edge caused by marsh fragmentation and high rates of flooding when young recruits arrive in estuaries makes marsh systems valuable habitats for transient fishery species such as penaeid shrimps, blue crab, and perhaps other species. The question of how S. *alterniflora* can apparently survive under very high flooding regimes would seem important, because the role of submergence and flooding in plant survival appears complicated (Mendelssohn and Morris 2000). Salt marsh in Galveston Bay functions more like seagrass; and you can often find shoal grass (*Halodule wrightii*) growing with S. *alterniflora* at the marsh edge. When I wrote one paragraph about the role of inundation

and waterlogging on *S. alterniflora* survival in the Discussion of a recent paper (Minello et al. 2012a), a reviewer suggested that I should stick to fisheries. Perhaps true, but I believe that the role of tidal flooding duration and frequency on marsh plant survival still has not been adequately addressed.

Many of my colleagues like to insert sayings or quotes at the end of their email messages that are reflective of their attitudes or scientific beliefs. My favorites might not be appro- priate here since they are *Deep Thoughts* by Jack Handey, but this quote from Lewis Carroll seems appropriate for many of us mapping EFH.

> "He had bought a large map representing the sea, without the least vestige of land: And the crew were much pleased when they found it to be a map they could all understand." *(Carroll, L. 1876, The Hunting of the Snark)*

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