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The Role of Nearshore Ecosystems as Fish and Shellfish Nurseries

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SUMMARY

Coastal ecosystems provide many vital ecological and economic services, including shoreline protection, productive commercial and sport fisheries, and nutrient cycling. Key nearshore ecosystems such as seagrass meadows, marshes, and mangrove forests are particularly valued for their extremely high productivity, which supports a great abundance and diversity of fish as well as shrimp, oysters, crabs, and other invertebrates. Because of the abundance of juvenile fish and shellfish they contain, nearshore ecosystems are widely considered "nurseries." The nursery role of coastal estuaries and marine ecosystems is well accepted by scientists, conservation organizations, fisheries managers, and the public, and it is often cited to support protection and conservation of these areas.

Nonetheless, comparatively little money and effort is being directed at protecting and managing these ecosystems. Until recently, even fisheries managers have largely ignored the issue of identification and conservation of juvenile habitat. This neglect, combined with intense pressures from human activities, is causing continued decline in vital nearshore habitats. We believe a better understanding of habitats that serve as nurseries for marine species is needed to help prioritize the limited funding and effort available for their protection and management.

Based on the scientific evidence, we conclude that:

- The concept of nursery habitat has been poorly defined.
- Lack of a clear definition has hindered identification of valuable nursery habitats.
- There is variation between and within ecosystems in their value as nurseries, and the nursery value of seagrass meadows, wetlands, and other ecosystems varies geographically.
- Many ecosystems such as oyster reefs and kelp forests have been relatively unexamined as nurseries.
- A better understanding of the factors that create site-specific variability in nursery quality will help prioritize efforts to halt their decline.

We suggest as a testable hypothesis that a nearshore habitat serves as a nursery for juveniles of a particular fish or invertebrate species if it contributes disproportionately to the size and numbers of adults relative to other juvenile habitats. The disproportionate contribution to the production of adults can come from any combination of four factors: density, growth, and survival of juvenile animals, and their movement to adult habitats. We further suggest that in future research on putative nurseries:

- It is not sufficient to measure a single factor such as density of juveniles.
- Researchers must compare multiple habitats, and an area should be considered important nursery habitat only if it produces relatively more adults per unit of area than other juvenile habitats the species uses.
- Despite the difficulties, researchers must track the number of individuals that move from juvenile to adult habitats; this number is the best measure of nursery value.
- Researchers should examine the factors that contribute to local variations in the value of nursery habitat. For example, not all marshes function equally as nurseries. An understanding of local variations could also help to explain regional changes in the nursery value of some habitats.

Conservation and management organizations now commonly consider all seagrass meadows and wetlands as nurseries, an assumption that may hinder the protection of other ecosystems vital to the protection of marine biodiversity as well as commercial fishery stocks. In the past, management effort has often focused on the restoration of these ecosystems. Future research needs to be devoted to measuring whether restoration reinstates the functional value of ecosystems as nurseries. Currently, results of restoration efforts are equivocal at best. Where restoration and mitigation cannot be shown to return nursery value, more effort should be focused on conservation. Better research and a clearer understanding of nursery habitats will allow more efficient use of limited money, time, and effort in conservation and management and contribute to the development of true ecosystem-based management of coastal resources.

Cover Photos (clockwise from top left) - Female blue crab in a seagrass meadow (courtesy Bob Orth); marsh loss from channel dredging and subsidence south of New Orleans (courtesy Terry McTigue, NOAA, National Ocean Service); mangrove roots provide habitat for fish and shellfish (courtesy NOAA); a happy fisherman with a 6.3 pound red drum (courtesy Charles Gardner, NOAA); rockfish in a California giant kelp forest (courtesy Morgan Bond).

The Role of Nearshore Ecosystems as Fish and Shellfish Nurseries

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INTRODUCTION

Nearshore ecosystems such as seagrass meadows, marshes, and mangrove forests supply many vital ecological services in coastal waters, including shoreline protection, commercial and sport fisheries, and nutrient cycling. Most notably, these ecosystems provide food and refuge that supports a great abundance and diversity of fish as well as shrimp, oysters, crabs, and other invertebrates. Because of this increased productivity and survival, nearshore estuarine and marine ecosystems are often considered "nurseries" for juvenile fish and shellfish. Indeed, the role of these nearshore ecosystems as nurseries is an established ecological concept, accepted by scientists, conservation groups, fisheries managers, and the public, and it is often cited as justification for the protection and conservation of these areas.

Figure 1 – Marshes provide vital ecological services, including serving as nursery habitat for fish and shellfish. Despite their importance, these ecosystems are threatened by drainage, development and pollution.

Despite wide acceptance of the nursery role of these ecosystems, however, comparatively little funding is applied to their conservation, management, or restoration. Most fisheries management emphasizes stock-recruitment models that focus on larval and adult populations rather than the protection of juvenile habitats. Meanwhile, the nearshore ecosystems that contain these juvenile habitats continue to decline – in some cases, precipitously. Both historically and currently, in fact, nearshore ecosystems are probably the marine environments hardest hit by human activities (Figure 1). The impacts come from coastal development; dredging, filling, and draining of wetlands; hardening of shorelines with riprap or concrete; upstream dams and diversions that alter freshwater inflow; land-based pollution; trawling of the seabed; and overfishing.

Unfortunately, the limited conservation and management efforts that are being undertaken in the coastal zone are applied piecemeal, with few clear priorities about where funding should be directed. Halting the decline in nearshore ecosystem integrity will require a better system for prioritizing where to spend limited time, money, and effort.

One problem in setting priorities, however, is that the concept of nursery habitat has rarely been defined clearly, even in research studies that purport to test it. There is also growing recognition that there are exceptions to the nursery role concept and that not all seagrass meadows and wetlands serve as nurseries. In addition, different ecosystems — and even different sites within them — vary in their value as nurseries. On the other hand, the nursery value of many ecosystems, such as oyster reefs and kelp forests, has very likely been underestimated. This ambiguity about the ecosystems that contain important nursery habitat hinders the effectiveness of the concept as a tool for prioritizing management.

This article does not address the question "Are wetlands and seagrasses important?" The answer to that is clear: There is undeniable evidence of their ecological and economic importance, aside from their potential as nurseries. However, we believe that better definition, identification, and understanding of nursery habitats will help us to set more effective targets for conservation and management of critical coastal ecosystems. Further, we believe a focus on nursery habitat for juveniles is necessary for the development of real ecosystem-level management of fisheries and other coastal resources. This report seeks to redress the ambiguities concerning nursery habitat by tracing the history of the nursery-role concept, developing clear guidance on how to assess which areas actually serve as nurseries, and discussing how such assessments can be used to focus efforts in research, conservation, restoration, and management.

HISTORY OF THE NURSERY-ROLE CONCEPT

The concept that certain coastal ecosystems serve as nurseries was first put forth nearly a century ago in the case of invertebrates, such as crabs and shrimp, and in fishes with complex life cycles – meaning their larvae move into coastal waters, metamorphose, grow to subadult stages, and then move to adult habitats (see Box 1). The concept has become so pervasive that some researchers have termed it a "law."

Early on, researchers considered the entire estuary to be the nursery. Later, however, the focus shifted to specific areas within estuaries as nurseries — especially tidal marshes, mangrove forests, and seagrass meadows — because evidence suggested that these supported much greater densities of organisms than adjacent unvegetated areas (those without large aquatic plants such as grasses or reeds). Most research to date has addressed the potential of wetlands (here defined as salt marshes and mangroves) and seagrass meadows to serve as nurseries. Thus, we concentrate our discussion on those ecosystems, drawing examples from other ecosystems when possible and noting that the potential nursery value of some of them — for example oyster reefs — has not received due recognition. We also focus our discussion on a particular life history stage, the juvenile stage, because this stage is directly affected by the quality of nursery habitats. We recognize however that effective conservation and management efforts must also consider other life history stages (for example larval, adult, and spawning stages).

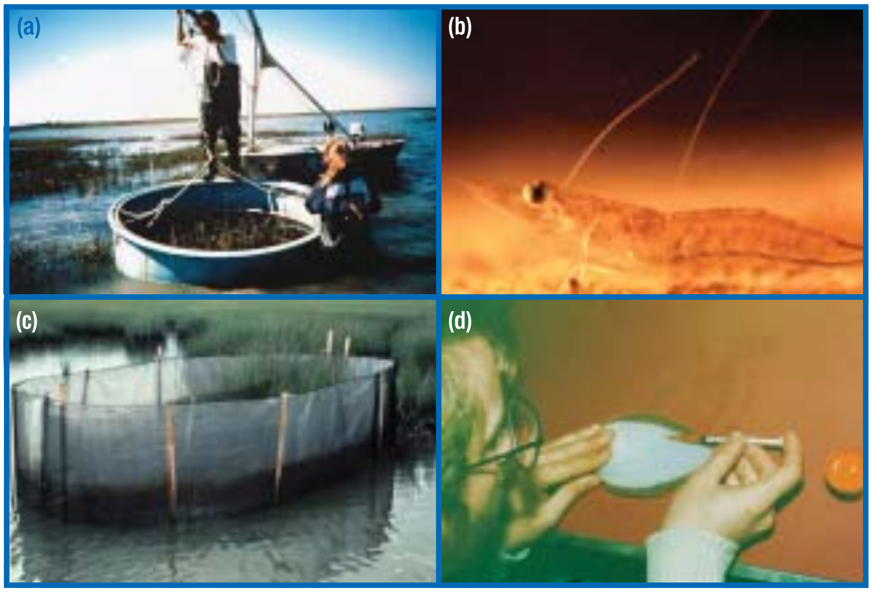

Figure 2 – Field experiments and observations used to assess whether some habitats serve as nurseries: (a) a drop trap used to compare density of juvenile animals between marsh and nearby unvegetated habitats; (b) a tethered shrimp used to assess differences in survival between sand, seagrass, and marsh habitats; (c) cages used to examine shrimp growth between marsh and nearby unvegetated habitats; (d) a juvenile summer flounder being injected under the skin with a nontoxic paint marker to allow researchers to track its movement patterns (from Beck et al 2001 *BioScience*).

Seagrass meadows and wetlands have been identified as nurseries in part because they export essential nutrients — carbon, nitrogen, and phosphorus — to coastal food webs. This export may occur when individual animals move out of these ecosystems, when predators move in to prey on organisms dwelling there, or when estuarine waters rich in dissolved and particulate organic matter outwell into coastal seas. This transfer of productivity from near-shore ecosystems to ocean food webs is undoubtedly important. Nonetheless, we focus here on the direct effects of these ecosystems on the productivity of individual species of fish and invertebrates, as opposed to their contributions to the productivity of coastal oceans in general.

Most studies of the nursery-role concept have examined the effects of seagrass meadows or wetlands on one of four factors: the density, survival, or growth of juveniles, or the movement of individuals to adult habitats (Figure 2). Generally, a habitat has been called a nursery if juveniles of a fish or invertebrate species occur at higher density, avoid predation more successfully, or grow faster there than in a different habitat.

Animal densities: Most studies have focused on the effects of seagrass meadows or wetlands on the density of a particular species. The evidence usually indicates that the density of fish and invertebrates is higher in the vegetated habitats they occupy than in their unvegetated habitats.

Juvenile survival: The few studies that have focused on differences in juvenile survival among wetlands, seagrass meadows, and other areas also indicate that survival of a species is generally greater in vegetated than in unvegetated habitats.

BOX 1 – Ecosystems and Habitats

Throughout the paper, the term ecosystem is used to identify characteristic assemblages of plants and animals and the physical environment they inhabit (e.g., marshes or oyster reefs). The term habitat refers to the area used by a species, with modifiers added to identify the particular habitats used by an animal. For example, the blue crab, *Callinectes sapidus*, has a seagrass habitat and a marsh habitat, which refer to particular portions of seagrass and marsh ecosystems, respectively, used by the crab.

Growth: Even fewer studies have focused on the effects of wetlands and seagrass meadows on the growth of fish and invertebrates. What evidence there is regarding growth in seagrass meadows is surprisingly equivocal. Only about half of the studies report that the growth rate of individuals is higher in seagrass habitats than in adjacent habitats.

Migration to adult habitats: Finally, only a handful of studies have attempted to determine whether the juveniles of a species move successfully from putative nursery habitats to adult habitats. The evidence that supports successful movement of seagrass- or wetland-associated juveniles to adult habitats is largely indirect, both because such movement data are difficult to obtain and because there has been a dearth of communication between benthic ecologists (who study nearshore ecosystems) and fisheries biologists (who monitor adult stocks).

Recently, several authors of this report quantitively compared evidence for the nursery role of marshes, mangroves, and seagrass meadows. While they found no studies that definitively tested the nursery role concept, they were able to integrate the results of these previous studies and assess whether they support the proposition that these ecosystems provide nurseries.

A review of major results from more than 200 relevant papers on seagrass meadows supported the notion that abundance, growth and survival of juveniles were greater in seagrass than in ecosystems such as sand or mud bottoms without plants. Abundance data also suggested that seagrass beds in the Northern Hemisphere might be more important as nursery areas than those in the Southern Hemisphere. Few significant differences were found in abundance, growth or survival of juveniles when seagrass meadows were compared to other structurally complex ecosystems such as oyster or cobble reefs or kelp beds.

A review of studies comparing salt marshes against other ecosystems found that based on fish density, ecosystems could be ranked from highest to lowest nursery value as: seagrass, marsh edge, open water, macroalgae (seaweed), oyster reefs, and inner marsh. Fewer studies were available comparing growth or survival of juveniles in salt marsh versus other ecosystems. When density, growth, and survival are all considered, the relative nursery value of salt marshes for free-swimming organisms such as fish appears higher than open water but lower than seagrass.

A third review of studies involving mangroves showed that animal densities found in mangroves were usually lower than those in seagrass meadows, coral reefs, and marshes. However, mangrove roots and debris did provide substantial refuge from predators and enhanced overall survival of young animals. There was very little useful data to evaluate whether mangroves serve as nurseries, and the evidence available was not sufficient to support the supposition that mangroves

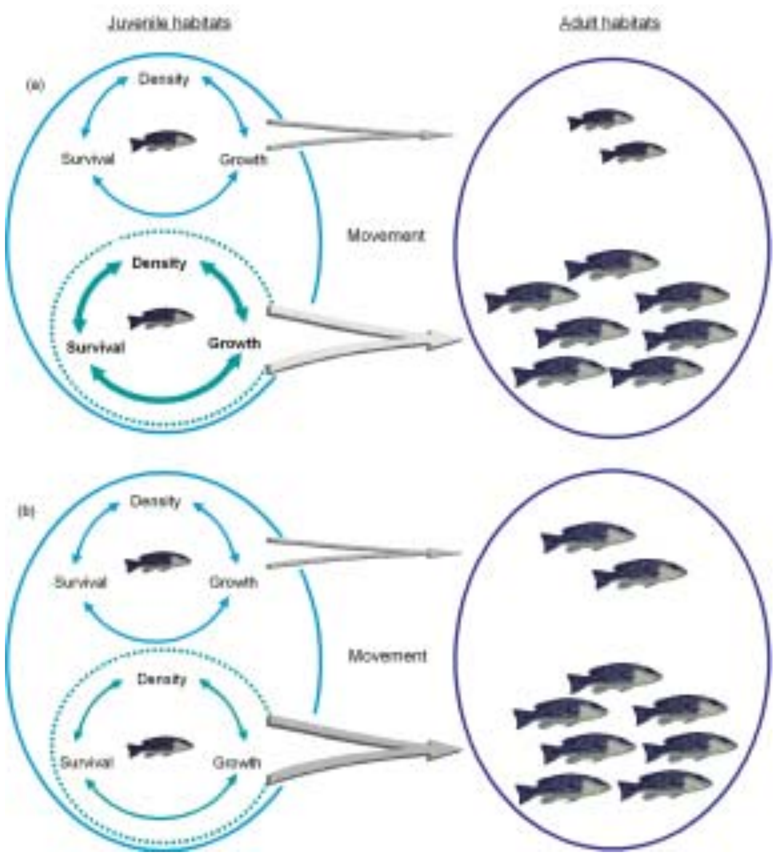

Figure 3 – A representation of the factors operating in juvenile and nursery habitats. The thickness of the arrows indicates the relative contribution from each factor to the replenishment of adult populations. A nursery habitat (dashed oval) supports a greater than average combination of increased density, survival, and growth of juveniles and movement to adult habitats. (a) All four factors are greater in the nursery versus other juvenile habitats. (b) Only one of the four factors, in this case movement, is greater in the nursery versus other juvenile habitats (from Beck et al 2001 *BioScience*).

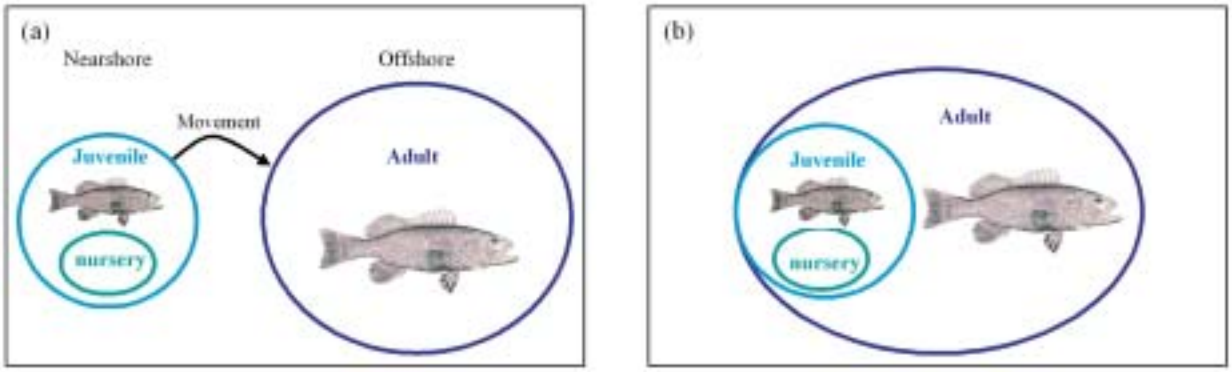

Figure 4 — Relationship between juvenile, nursery, and adult habitats. The square represents all habitats. The ovals represent the portions of habitats used during juvenile and adult stages. Nursery habitats are a subset of juvenile habitats. (a) Classic concept of species that have nursery habitats. (b) General concept of species that have nursery habitats. There can be overlap in the habitats that juveniles and adults use, but there must be some difference between juvenille and adult habitats for a species to be considered to have a nursery habitat (from Beck et al 2001 *BioScience*).

provide better nurseries than other structurally complex ecosystems; more data are needed.

In summary, the results of these three reviews indicated that overall seagrass meadows usually showed the highest value as nurseries, followed by marshes. In many comparisons, however, marshes and seagrass meadows were not much different than other structurally complex ecosystems such as oyster reefs.

There is growing recognition that some nearshore ecosystems in specific regions do not provide vital nursery habitat. For example, few commercially important species of fish and invertebrates appear to rely exclusively on seagrass meadows in the coastal waters of Massachusetts or New Jersey. Although most of these species use seagrass meadows opportunistically, they can survive well in other areas, too. Likewise, seagrass beds in southern Australia are not always better nurseries than nearby unvegetated habitats. For example, a study on the Australian blue groper (*Achoerodus viridis*) indicated that additions to the offshore adult population came primarily from young that settled in offshore rocky reefs, not from the abundant young in inshore seagrass beds. Indeed, a recent planning document produced for the Australian Fisheries Research Development Corporation concluded that there was very little strong evidence that Australian seagrass provided critical nursery habitat for the majority of Australian finfish species

DEFINING AND IDENTIFYING VALUABLE NURSERY HABITATS

It is not surprising that evidence for the role of certain ecosystems as nurseries is sometimes scant or contradictory. There are exceptions to any broad ecological concept. However, the problem of ambiguous evidence is exacerbated by the fact that the nursery-role concept is not based on a clearly defined hypothesis and has therefore been difficult to test directly.

The underlying premise of most studies that examine nursery-role concepts is that some nearshore, juvenile habitats contribute more than others to the production of new adults. From this premise, we have developed a hypothesis from which clear and testable predictions can be made: A habitat is a nursery for juveniles of a particular fish or invertebrate species if it contributes disproportionately to the size and numbers of adults relative to other juvenile habitats. The disproportionate contribution to the production of adults can come from any combination of four factors: (1) density, (2) growth, (3) survival of juveniles, and (4) movement to adult habitats (Figure 3). Studies that examine only one of these four factors in putative nursery habitats cannot be considered sufficient.

Below we describe a number of key considerations that should be taken into account when testing the nursery-role hypothesis — considerations that have frequently been overlooked in the past.

The nursery-role concept is relevant only to species with a particular set of life history strategies that involve some separation between juvenile and adult habitats (Figure 4). The original research on nurseries focused on an idealized or classic life history strategy: Juveniles grew up in nearshore marine or estuarine habitats and then rapidly moved to completely different offshore adult habitats. However, many species with substantial overlap in juvenile and adult habitats have historically been thought to use nurseries. In blue crabs, for example, juveniles and adults often occupy the same habitats, but females move to non-juvenile habitats (usually the mouths of estuaries) to release larvae. Some species such as spiny lobsters do not move directly from juvenile to adult habitats but move gradually between them, and they also have been considered to have nursery habitats. We suggest that species must have at least some disjunction between juvenile and adult habitats to be considered to have nursery habitats, and in most cases, movement to non-juvenile habitat is associated with reproduction.

Of course, marine species display many other life history strategies, and the nursery-role hypothesis does not imply that habitats such as seagrass meadows do not have important effects on species that spend their entire lives there. The nursery concept has not generally been applied to these species. For species where there is no distinction between juvenile and adult habitats, there is no need (indeed it is not possible) to focus specifically on nursery habitats. Based on our definition, examples of taxa that do not have nurseries per se include bay scallops (*Argopecten irradians*), killifish (*Fundulus*), bay anchovy (*Anchoa mitchilli*), and amphipods (small crustaceans such as sand hoppers). Examples of taxa that do use nurseries are clawed lobster (*Homarus americanus*), eels (*Anguilla americana*), red drum (*Sciaenops ocellatus*), gag grouper (*Mycteroperca microlepis*), blue groper, pink snapper (*Pagrus auratus*), luderick (*Girella tricuspidata*), tarwhine (*Rhabdosargus sarba*), blue crabs (*Callinectes sapidus*), brown shrimp (*Farfantepenaeus aztecus*), flounder (*Paralichthys* spp.), pinfish (*Lagodon rhomboides*), striped mullet (*Mugil cephalus*), and gray snapper (*Lutjanus griseus*).

Multiple habitats can serve as nurseries, and individuals do not have to live within a habitat to receive benefit from it. During their juvenile stage, individuals will often move between multiple habitats and receive benefits from each. In some cases, individuals may not even have to reside in a habitat to receive benefits from it (Figure 5). For example, weakfish from the middle of Delaware Bay do not occur directly within marshes, yet they feed on prey that derive their nourishment from marshes, as evidenced by the chemical signatures of marsh nutrients found in weakfish tissues.

A definitive test of the nursery-role hypothesis requires a comparison among all habitats that juveniles use (Figure 6). Comparisons of nursery value among putative nursery habitats have usually involved only vegetated and unvegetated habitats, even though individual species may use many different habitats. Thus, seagrass meadows or wetlands may be less important as nurseries in regions where animals use alternative habitats successfully. For example, in bays in southern Australia and in the northeastern United States, a species may be found in many habitats — cobble, rocky reef, oyster reef, kelp bed, sandy or muddy bottom — in addition to marsh and seagrass habitats. To determine which, if any, habitats serve as nurseries, researchers must study all of a species' juvenile habitats. Indeed, these analyses are likely to reveal that many other types of habitats, including oyster reefs, kelp forest canopies, and some offshore habitats, also serve as nurseries.

Nursery habitats are a subset of juvenile habitats. Any habitat that makes a greater-than-average contribution to the recruitment of adults should be considered a nursery habitat. Thus, some portions of juvenile habitats, but not all, can be considered nurseries (Figure 4). Juvenile habitats that are found not to be nurseries can and often do contribute individuals to adult populations, but they make a less than average contribution when compared with other juvenile habitats. If many habitats are examined, it should be possible to identify and focus conservation and management efforts on those that make the greatest contribution to adult recruitment.

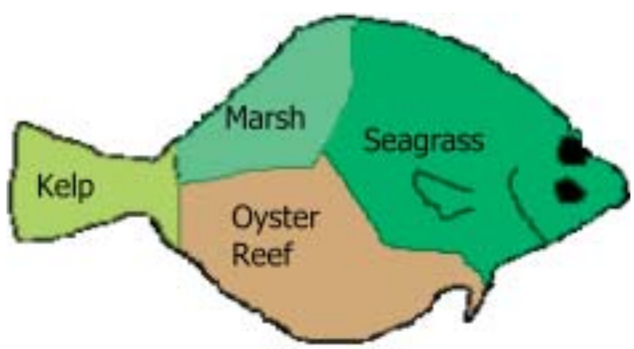

Figure 5 — An individual fish may gain contributions from a variety of different habitats during its juvenile stage, as illustrated stylistically above in the pie (fish) chart that shows the proportional contribution of different habitats to the growth of a given fish. These contributions from multiple habitats can be revealed through isotopic signatures.

Examination of a single factor such as the density of juveniles in various habitats does not provide a conclusive test of the nursery value of a habitat. In the overwhelming majority of studies, a habitat is suggested to be a nursery largely because it supports high densities of juveniles relative to another habitat. The unstated but rarely tested premise in most of these studies has been that, all else being equal, habitats with higher densities of juveniles are likely to make a greater contribution to the production of adults than habitats with lower densities. This correlation may hold true in many cases, but there are likely to be important exceptions. For example, some sites may be well placed to receive an influx of larvae and thus harbor high densities of juveniles, but conditions at these sites may also be such that juveniles grow slowly or face a risky or difficult time moving to adult habitats.

The nursery role of habitats must be compared on a unit-area basis. Even if a habitat covers only a small area, it should be considered an important nursery habitat if it produces relatively more adult recruits per unit of area than other juvenile habitats that a species uses. This distinction is important in setting conservation and management priorities. It is more important to conserve, prevent destruction of, restore, or otherwise manage habitats that contribute disproportionately to the production of adults. This need is even more pressing if the nursery habitats are relatively uncommon. It is possible that common habitat types may make important contributions to the recruitment of adults even if the density of individuals per area is low, simply because the habitats are widespread. We predict, however, that there will be few cases where habitats that have lower densities and often lower survival and growth rates of individuals will make significant contributions to adult recruitment simply because they are widespread. And if these habitats do make significant contributions solely because of their large areal coverage, they should be regarded not as nurseries but as important juvenile habitats.

The best single measure of the contribution from juvenile habitats is the total biomass of individuals added to adult populations. The nursery habitats for a species are those that are the most likely to contribute to future populations. This contribution should be a function of both the size and number of individuals added to adult populations, because both of these factors affect survival, growth, and reproductive success in the adult habitats. The best integrative measure of this potential contribution from juvenile habitats to future generations, then, is the total biomass of individuals being added to adult populations.

The movement of individuals from juvenile to adult habitats must be measured. There are very few studies on movement patterns, and this is a vital missing link in our understanding of nurseries. Movement of individuals is one of the most difficult variables to measure in ecology. Fortunately, vast improvements in technology — archival data loggers, stable isotopes, genetic markers, and otolith microchemistry — now enable researchers to track and infer movements.

FACTORS THAT CONTRIBUTE TO SITE-SPECIFIC VARIATION IN NURSERY VALUE

The nursery value of seagrass meadows, wetlands, and other ecosystems may vary geographically, as noted above.

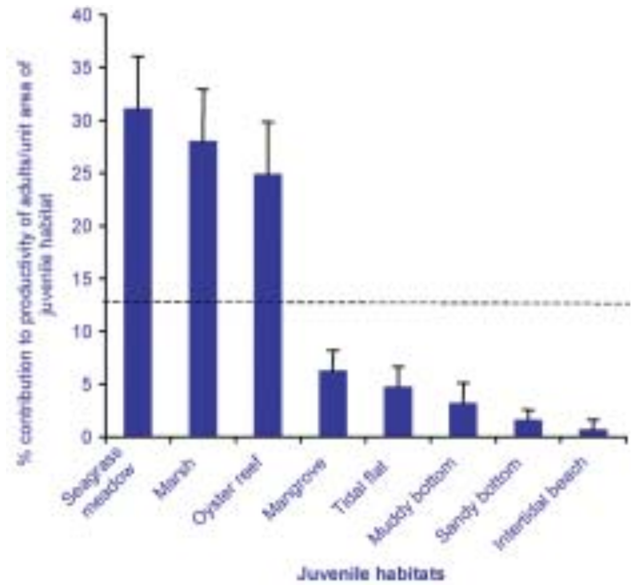

Figure 6 – A hypothetical comparison of the nursery value of several different habitats for one particular fish species. The dashed line represents the average percentage productivity of adults per unit area from all the juvenile habitats. In this example, seagrass meadows, marshes, and oyster reefs are nursery habitats for this fish species while the other five are not. Different fish species are likely to have different nursery habitats (from Beck et al 2001 *BioScience*).

Recent analyses suggest, for example, that seagrass meadows are more important as nurseries in the tropical Caribbean than they are in the Indo-Pacific region, and likewise more important as nurseries in the United States than in Australia. Even within the United States, seagrass meadows in warm temperate regions may serve as better nurseries than those in cool temperate regions. For marshes, evidence suggests these ecosystems may be more important as nurseries in the Gulf of Mexico than in the U. S. South Atlantic.

Unfortunately, this apparent geographic variation creates disagreements about the importance of nurseries in general. Much of the variation between regions could be understood, however, by examining factors that contribute to local variation within an estuary in the value of nursery habitat. For example, even different seagrass meadows within a single

Table 1 — Factors that create site-specific variation in the nursery value of habitat (from Beck et al 2001 *BioScience*).

Biotic	Abiotic	Landscape
Larval supply Structural complexity Predation Competition Food availability	Water depth Physical-chemical (dissolved oxygen, salinity) Disturbance patterns Tidal flows	Spatial pattern (size, shape, fragmentation, connectivity) Relative location (to larval supply, other juvenile habitats, adult habitats)

estuary vary in their value as nurseries for a specific fish or shellfish species. Factors that can create this site-specific variation in nursery value can be grouped into three broad categories: biological, physical or chemical, and landscape (Table 1).

Biological factors

The presence and activities of other organisms in a habitat can influence its nursery value for a species. For example, studies have found that predation on target species is lower in seagrass beds that are more structurally complex, which suggests that these more complex habitats may increase survivorship for juveniles of many species. The initial density and size of juveniles is often strongly determined by the abundance and size of larvae that settle within habitats, but factors that control larval supply are rarely considered when evaluating how well habitats function as nurseries. Other biological factors that affect the nursery value of a specific site include food availability and competition for food.

Physical and chemical factors

Chemical factors such as salinity also appear to influence site-specific variation in nursery value. For example, the densities of many species within marshes are highly dependent on salinity levels. Other chemical and physical factors that affect the nursery value of a site may include water depth, oxygen levels, tidal flows, and vulnerability to storms, floods, and other disturbances.

Landscape factors

Landscape-level factors also can affect the nursery value of sites. For example, the relative location of seagrass beds in an estuary can affect the density of fish species; some seagrass beds near the site where larvae enter estuaries have higher densities of fish than similar beds farther up the estuary. In Exuma Sound in the Bahamas, the proximity of nursery habitats to adult habitats seems to influence the abundance of adult lobsters by affecting their success in moving between habitats. The delivery of larvae to a site – and thus the initial juvenile density — is strongly influenced by its location relative to large water movements such as upwelling or retention zones. Nearby habitats also influence a site's value as a nursery. For example, both the density and growth of pinfish has been found to be higher in marshes adjacent to seagrass beds than in marshes adjacent to unvegetated bottom.

IMPLICATIONS FOR RESEARCH

Better and more consistent tests of the nursery-role hypothesis will help us identify the most important nursery habitats. More importantly, they will reveal the factors that make some sites more successful than others in the production of juveniles that survive to replenish adult populations. These tests should also provide a better indication of which species of fish and shellfish depend on particular nursery habitats.

Several practical considerations should guide future research on the nursery-role concept. First, more than one factor must be considered. Ideally, all four factors—density, growth, survival, and movement—would be examined in a study of putative nursery habitats, although doing so may be difficult. Nonetheless, researchers cannot continue to be satisfied with single-factor studies in this field. Multifactor experiments can also be valuable because they often lead to useful insights about interactions between factors such as density and growth.

Second, researchers must consider multiple habitats. Although most species are found in more than one or two habitats, surprisingly few studies make comparisons between more than two potential nursery habitats.

Third, researchers must attempt to quantify the movement of individuals between juvenile and adult habitats with all available tools. Refinements in tagging and chemistry can help substantially in identifying the sources of individuals that show up in adult habitats. These techniques can be labor intensive and expensive, however, and they involve more laboratory than field time, which would require a major shift in many research programs. Nonetheless, it should be possible to design simple field studies to examine the movement of juveniles. It is surprising, for example, that so few studies examine movements of juveniles of a particular size or at a specific season from the mouths of estuaries towards adult habitats.

Fourth, although we have mainly discussed direct methods of study in this report, correlative and case study analyses can also yield many useful insights. For example, many studies have looked for correlations between inshore habitat loss and offshore fisheries production. The link currently appears weak (see Box 2), and these correlative analyses cannot provide confirmation of the existence of nursery habitats. However, they do provide relevant observations on potential nurseries at scales that are ecologically and economically important.

Finally, examining the factors that contribute to local variations in the value of nursery habitat within an estuary can help to develop testable predictions about variations between geographic regions.

IMPLICATIONS FOR CONSERVATION, RESTORATION, AND MANAGEMENT

Degradation of the world's coastal ecosystems continues at an alarming rate. Estuaries may be some of the most degraded

BOX 2 – The Paradox of Wetland Loss and Fishery Resources

Most fish and shrimp species harvested off the Southeastern coast of the United States spend part of their life cycle in estuaries, and coastal wetlands appear to be vitally linked to the productivity of this fishery. The Southeast coastline hosts vast expanses of marshland, seagrass meadows, mangrove forests, and some of the most highly productive fisheries in the country. On a global scale, researchers have long recognized that the extent of coastal wetlands is positively related to fishery harvests. On a local scale, researchers have documented high densities of juvenile fishes, shrimps, and crabs in seagrass meadows and marshes compared with nearby habitats largely bare of plant cover.

The linkages between wetlands and fishery productivity, however, can be complex. Availability of coastal marshes to fishery species, for instance, is determined by tidal flooding patterns, the amount of "edge" habitat where the marsh meets open water, and the extent of the connections between interior marsh and the sea. Low-elevation marshes in the northern Gulf of Mexico are flooded almost continually during some seasons and are extensively fragmented, providing maximum access for young fishery organisms. In contrast, marshes along the South Atlantic coast have relatively little marsh/water edge and appear to be infrequently flooded. The density of commercially valuable species using the marsh surface also varies between these two regions: Densities in the Gulf are generally an order of magnitude greater than those on the Atlantic coast. We now believe that these differences in wetland availability and use are at least partially responsible for the higher landings of estuarine-dependent fish and shrimp species in the Gulf of Mexico compared with the South Atlantic.

Given the linkages between wetlands and fishery production, we might expect dramatic declines in estuarine-dependent fisheries to follow the extensive loss of coastal marsh that is occurring in the northern Gulf of Mexico. However, over the past 20 to 30 years, productivity and landings of three dominant fishery species — brown shrimp, white shrimp, and menhaden — in the northern Gulf of Mexico have increased. In contrast, production of these species did not increase on the Atlantic coast where wetland loss was relatively low compared with the Gulf. We are left with a paradox: Increased production of fishery species appears to follow the degradation of their habitat. This paradox may be a temporary phenomenon, however, and the explanation lies in the process of wetland degradation itself. Wetland losses in the northern Gulf are caused largely by coastal submergence, canal dredging, levee construction, and erosion. The result of these activities is that marsh flooding increases, fragmentation and habitat edge increase, zones of saline and brackish wetland expand, and connections with the sea are shortened. All of this increases the availability and value of the remaining marsh and may be supporting short-term increases in fishery production. However, continued wetland loss is likely to overcome any short-term benefits of habitat degradation and bring about future declines in production of wetland-dependent fish and shrimp.

environments on earth because they have been focal points for human colonization for centuries. The threats to estuaries and other nearshore ecosystems today arise from a vast range of human activities, from coastal development and industrial fishing to upstream dams and water diversions. The impacts include habitat loss and degradation, pollution, eutrophication, changes in freshwater inflows or tidal patterns, loss of fish and shellfish populations, invasive species and changes in marine community structure (Table 2).

Interest in conserving and managing coastal waters is intense and widespread, but funds remain limited and must be targeted judiciously. Conservation and management organizations now commonly consider all seagrass meadows and wetlands as nurseries. These broad declarations may be useful for generating public interest, but they hinder the actual work that needs to be accomplished. A clearer understanding of the habitats that serve as nurseries for specific species, and the factors that make some sites more valuable as nurseries than others, will allow more efficient use of limited money, time, and effort in conservation and management. For example, if it were shown that the best seagrass nurseries for a valued species were large areas near sources of larval influx and in close proximity to adult habitats, then preservation or restoration efforts could be targeted preferentially at such sites. Although some information of this nature is available, it has not been applied specifically to the identification of critical sites for management.

That said, however, it would be imprudent to wait for irrefutable evidence of a given area's function as a nursery before taking action to conserve, manage, or restore it. Rather, the most cautious and prudent course is to act on current knowledge of an area's potential as a nursery. Substantial evidence, for instance, already supports the belief that some seagrasses and wetlands are likely to be high-priority nursery habitats. Seagrass meadows and wetlands, of course, have been the focus of most work on nurseries, and in most cases this emphasis appears justified. However, future research is also likely to show that previously ignored areas such as oyster reefs and kelp beds also serve as nurseries and therefore should be better conserved and managed.

Table 2 — Key threats to coastal ecosystems.

Key Threats to Coastal Ecosystems
• Habitat loss—coastal development, dredging, filling, draining
• Habitat alteration—hardening of shorelines, fragmentation (although fragmentation is not an issue for many marine ecosystems, it may be a critical problem for nearshore nurseries)
• Altered freshwater inflow
• Altered saltwater flows
• Loss of water clarity (threatening grasses, kelps, and coral reefs)
• Eutrophication (leading to low oxygen conditions and increased algal blooms)
• Invasive species
• Overfishing and bycatch (leading to population loss and altered community structure)
• Trawling and other fishing gear impacts that alter or destroy habitat

Most of the limited funds available for managing nearshore ecosystems are currently spent on restoration. While some restoration efforts do succeed, many projects have not been sufficiently monitored to evaluate success or failure. Even so, it is clear that our ability to restore ecosystems such as salt marshes and seagrass meadows is quite limited. The goal of restoration should not be just to replant some species and create, for example, marsh gardens, but to document returns of species, communities, and ecological functions such as nursery services. Restoration of these functions, indeed, should be encouraged as a central goal of restoration efforts. We must also question the value of mitigation, given our limited ability to restore ecosystems. More effort should be devoted to conservation so that restoration is not required. We also need to apply new strategies to the protection of coastal ecosystems, including development of marine protected areas, leasing or ownership of submerged lands, and improvements in water quality.

A number of U.S. agencies are required by law to plan for identification and restoration of important coastal habitats, and the role of these habitats as fish and shrimp nurseries has provided a major impetus for such legislation. For example, the Magnuson-Stevens Fishery Conservation and Management Act requires the National Oceanic and Atmospheric Administration (NOAA) and other federal agencies to identify and protect "essential fish habitat." Further, the Estuaries and Clean Coastal Waters Act of 2000 allocates funds for estuarine restoration, and the Coastal Impact Assistance Act appropriates funds for conservation and restoration in U. S. coastal waters.

Unfortunately, conservation and management of nursery habitats is caught between many competing agencies that have responsibilities for the coastal zone. In the United States, these agencies include NOAA, the Environmental Protection Agency, and the Department of the Interior at the federal level, as well as state natural resource agencies and local land-use planning bodies. Establishment of a jointly funded nursery ecosystem management program across key agencies could greatly enhance management and protection of vital coastal assets.

Given our increasing ability to threaten marine species and drastically alter ecosystems — and our limited ability to correct our mistakes — we must plan to conserve and manage the marine environment with significantly more forethought than in the past. The conservation and management of nurseries is one of the few issues that unites most scientists, conservationists, and both recreational and commercial fishers, and this unity should be capitalized on to strengthen our efforts to protect vital coastal zones. A better understanding of nursery habitats should enable scientists and funding agencies to fill the gaps in our knowledge, help agencies and organizations better target their conservation efforts to protect marine diversity, and allow state and federal agencies and fishery management councils to make better regulatory decisions for fisheries management and habitat conservation.

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About the Science Writer

Yvonne Baskin, a science writer, edited the report of the panel of scientists to allow it to more effectively communicate its findings with non-scientists.

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