The Interface between Fisheries Research and Habitat Management

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Abstract.—Successful natural resource management requires a balance between the social and economic demands placed on the resource and the absolute biological limit to resource harvesting. We outline a procedure to assist managers in prioritizing scientific information in relation to this biological limit. All life history stages of a target species are considered, relative to their habitat requirements, and a determination is made whether or not there is an essential habitat for any of the life history stages. We define an essential habitat as being physically discrete and indispensable for the survival of at least one life stage of the target species. Managers determine if the essential habitat is vulnerable to anthropogenic impacts; the scientific community investigates the ramifications of a particular management strategy or studies the interdependence of life history stage and habitat. We suggest that economically important fisheries that have relatively small essential habitats and habitats that are important for more than one target species rank higher in terms of management priority. This scheme offers an objective way for managers to weigh social and economic demands against the biological constraints within which a sustainable fishery must operate.
Many of the fisheries resources along the northeastern coast of North America are either overexploited or have already suffered stock collapses (Northeast Fisheries Science Center 1993; Sinclair 1993). Although overfishing has been implicated as the cause of the groundfish stock declines off the U.S. coast (Anthony 1993), there is concern that habitats are being lost, or at least compromised, because of adverse fishing practices (Messieh et al. 1991; Eleftheriou and Robertson 1992; Jones 1992), coastal development (Colgan 1992), and pollution (Longwell et al. 1992; Schaaf et al. 1993). These ancillary factors may ultimately prove to be more deleterious to stock restoration efforts than overexploitation. Habitat conservation is therefore becoming an increasingly important focus of debate. For example, discussions regarding reauthorization of the Fishery Conservation and Management Act of 1976 in the USA include the recommendation that conservation of habitat for living marine resources be added as an additional national standard for fisheries conservation and management (American Fisheries Society 1993). Canadian fish habitat management policy, introduced in 1986 (Department of Fisheries and Oceans 1986), had for its ultimate objective a net gain in productive fish habitat and led to new strategic relationships between habitat managers, scientists, and stakeholders (Ducharme 1992). Selecting the appropriate degree of habitat protection, which can range from seasonal and areal spawning closures to establishing nonextractive refugia, is the challenge facing management. Over-protection unnecessarily restricts the fishing industry while reducing the credibility of the scientific community (if science is the basis for the management decision). Inadequate protection allows the continued downward spiral in fishery production and demonstrates an inability to logically develop applied research priorities aimed at habitat protection.

Fisheries research and management were discussed at a Gulf of Maine Habitat Workshop in Boothbay Harbor, Maine, in April 1994 (Stevenson and Braasch 1994). Ideas originally outlined at that workshop by an ad hoc working group on fisheries resources are incorporated and further developed in this paper. We present a flow diagram that organizes research priorities toward goals of habitat management. We also consider the research—management interface and suggest a way to develop management priorities in an ecological context by using examples from fisheries in the northwest Atlantic Ocean. The principles and suggested approach are, however, applicable to other marine and freshwater systems.

Among the goals of management are the conservation or protection of natural resources. In cases of habitat degradation, managers may consider means by which to restore resources. From a more proactive perspective, managers may wish to add to, or enhance, existing resources. Finally, management must attempt to maintain stable resource productivity and sustain resource quality through the control of human activity and the environment. This latter point, regarding quality, reflects concern about contaminant loading and pollution.

We consider these goals in the context of habitat as an essential resource for sustaining the production of commercially and recreationally important species. In many cases, knowledge of whether a particular habitat component is essential for a given species at any point in its life is poorly known. Obviously, such knowledge must be obtained, as must the geographic limits of the habitat component, before the vulnerability of the habitat to anthropogenic impacts is evaluated. Resource management suffers from a lack of species-specific habitat knowledge and is often viewed as reactive, focusing on economically based resource crises rather than on resource protection, restoration, or enhancement. For resource management to succeed, it is imperative that managers develop an ecological approach to resolving management problems to replace the economically driven approach.

Aquaculture development and wild-stock enhancement programs are also relevant in a consideration of habitat or natural resource management issues. The culture of a species depends upon a detailed knowledge of the particular suite of habitat characteristics that promotes optimal growth. In addition, sustainable development of aquaculture and the economic return from enhancement activities requires an understanding of a system's natural carrying capacity and the effect of in situ culture activities on this carrying capacity. Consequently, both aquaculture and enhancement may impinge on other fisheries and natural resources if they are established within another species' essential habitat. Nonetheless, for the purposes of this paper, aquaculture (including extensive enhancement programs) has been subsumed under anthropogenic impacts on wild-stock fisheries and is not considered explicitly.
ESSENTIAL HABITAT

Identifying Essential Habitats and Critical Life History Phases

The highest-priority research is to determine if there is an "essential habitat" for any fisheries species. We define essential habitats as geographically or physically distinct areas that one or more species finds indispensable for its survival at some phase in its life history. By defining essential habitat as discrete geographic areas, researchers provide managers with a definition of habitat that should be "manageable" in terms of decision making and policy enforcement.

To identify essential habitats, sufficient knowledge must exist to evaluate all major phases in the life history, representing both ontogenetic and functional shifts, for each species of interest. We propose that the importance of essential habitat be approached by developing a habitat–life history matrix for each species of interest (Figure 1).

In principle, the habitat–life history matrix integrates large-scale distribution (e.g., distance from shore, water depth, pelagic versus benthic) and local habitat characteristics (e.g., substrate characteristics, complexity, or both; see Brown 1993 for a habitat characterization scheme) with distinct ontogenetic or functional phases (see Langton and Watling 1990) in a species’ life history (e.g., egg, larvae, juvenile, adult). Known associations between life history phases and habitat can then be arrayed in the matrix. As part of this exercise, it is important to recognize whether a "critical phase" exists in the species’ life history and whether information about the habitat “requirements” during this phase is lacking. The critical phase is the time in the life history when cohort size is determined. The critical phase may or may not be related to an essential habitat; however, when it is, the importance of habitat is overriding. According to our definition, a species showing a broad habitat tolerance during the critical phase in its life history would not have an essential habitat. Management of such a species is unlikely to be successful if it is oriented strictly toward habitat. Instead, other management techniques may be required, such as broad-scale temporal or spatial prohibition of activities deemed detrimental to the critical life history phase. We use the American lobster *Homarus americanus* and the Atlantic cod *Gadus morhua* as examples of how to identify essential habitats (Figure 1).

American lobster larvae are released by ovigerous females either offshore or near shore (Harding and Trites 1988), but larvae settle in shallow subtidal or low intertidal habitats (Incze and Wahle 1991). Cobble substrata in particular support high densities of newly recruited American lobsters, although cobble beds are regionally restricted in areal extent (Wahle and Steneck 1991). Newly settled animals are highly susceptible to predation and require shelter such as that provided within the interstices of cobble beds (Wahle and Steneck 1992; Figure 1A). As American lobsters grow, their selection of benthic habitats is much less discriminating. The restricted area of the plot in Figure 1A represents the postlarval phase and identifies a critical phase in the American lobster’s life history (recruitment of the postlarvae to the benthos) and the presumptive essential habitat (shallow cobble substrata).

Eggs and larvae of Atlantic cod on Georges Bank have a ubiquitous pelagic distribution (Figure 1B). The distribution of settled juveniles, however, is severely restricted to the gravel pavement.

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**Figure 1.**—Habitat–life history matrices for (A) American lobster and (B) Atlantic cod showing the spatial relationships between ontogenetic changes (X1, youngest to X5, adult) in the animal’s distribution relative to the distance from shore, or water depth, and substrate complexity. The point X3 represents early benthic stages of both American lobster and Atlantic cod, which recruit to shallow cobble and gravel substrates that serve as essential habitats by affording protection from predators.

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on the northern edge of this offshore bank (Lough et al. 1989). Tupper and Boutillier (1995) have shown that young-of-year Atlantic cod settle equally to all bottom types, but predation mortality in structurally complex habitats is much lower than elsewhere (Gotceitas and Brown 1993). The gravel pavement on Georges Bank, by providing such complexity, allows a relatively large proportion of larvae to continue development. The resulting distribution of juveniles indirectly defines an essential habitat for a critical life stage. Myers and Cadigan (1993) have argued that population variability and regulation of demersal marine fish originate in early juvenile stages. They also found strong evidence of density-dependent mortality in these species, a mechanism that may represent a trade-off between refuge (habitat) use and feeding time in the face of predation risk (Walters and Juanes 1993). These results emphasize the importance of habitat quality and availability in determining the recruitment success of juvenile fishes.

Like American lobsters, Atlantic cod become much less specific in their habitat requirements as they grow. From Georges Bank, they generally extend their range off the top of the bank into deeper waters (Overholtz and Tyler 1985) and undertake larger-scale movements related to feeding and spawning. In other geographic areas, this dispersal could define an essential pelagic habitat based on thermal characteristics. For example, Atlantic cod strongly aggregate off Newfoundland (Rose 1993) and are vulnerable to intensive fishing pressure there. It has yet to be determined if Atlantic cod exhibit this same degree of aggregation on Georges Bank or in the Gulf of Maine, although anecdotal information suggests that they aggregate for spawning at predictable locations and times. Recent evidence suggests that geographic variation in timing and location (e.g., offshore versus inshore) of Atlantic cod spawning may explain some of the observed recruitment variability in the northwest Atlantic (Hutchings and Myers 1993; Hutchings et al. 1993).

Other examples of potentially essential habitats for commercially important species from the northwest Atlantic include the dependence of Atlantic herring Clupea harengus on gravel bottom in the Gulf of Maine for successful spawning (Stevenson and Knowles 1988); the restriction of sea scallops Placopecten magellanicus and Iceland scallops Chlamys islandica to high-energy sandy bottoms or coarse gravel bottoms; and the intolerance of these animals of fine sediments (Schneider et al. 1987; Langton and Uzmann 1989; Thouzau et al. 1991; Cranford and Gordon 1992); and the importance of nearshore nursery areas for juvenile fish and crustaceans (Weinstein 1979; Hae drich 1983; Rountree and Able 1992; Methven and Badjik 1994).

**Focusing Habitat-Related Research**

We developed a flow diagram that facilitates decision making regarding the conservation, protection, restoration, and enhancement of fisheries resources (Figure 2). It poses a series of questions and indicates the relevant research actions to be undertaken. What is known about a species' biology and ecology are first summarized in a species profile and arrayed in a habitat matrix. If an essential habitat is identified, habitat research (experimental and field) is required to develop a detailed characterization of the various abiotic (e.g., bottom type) and biotic (e.g., species interactions) factors that affect the target species' association with the habitat. If an essential habitat is identified, its areal extent and whether or not it is at risk must be determined. The flow continues through the development of a management regime that will balance the need for harvesting the resource against the manager's charge of protecting, restoring, and enhancing the fisheries.

**The Research–Management Interface**

Natural resource management plans require a balance between the social and economic demands placed on the resource and the absolute biological limit to resource harvesting. A scheme for determining this balance has been presented together with a series of research actions that feed into a management process, the anticipated result being a strategy to protect, restore, or enhance the living resource of concern (Figure 2). A fishing closure in Sheepscot Bay, Maine (Maine Department of Marine Resources, Regulation 34.05, Augusta) and a closure of areas I and II in the Gulf of Maine to fishing for haddock Melanogrammus aeglefinus (amendment 5 to the Northeast Multispecies Fishery Management Plan of the New England Fishery Management Council, Saugus, Massachusetts), promulgated to protect known groundfish spawning and nursery areas, are examples of the management side of such a process. These actions might also define essential habitats; however, these closures inevitably protect larger geographic areas than the essential habitat per se, and defining a closure on this basis is a manager's prerogative. Without an understanding of why fish congregate in specific areas (see Rose 1993), other than simply
to spawn or grow, the question of habitat essentiality and vulnerability resides in the realm of research.

Although matrix and flow diagrams help delimit a species' essential habitat, and an overlay of matrices demonstrates the potential biological importance of a particular habitat type for a multitude of species, these procedures do not rank the importance of these habitats for management purposes. Managers might consider relatively small essential habitats of economically important species as having the highest ranking, whereas widespread essential habitats of target species of low economic importance would rank lowest. Essential habitats that are used by several target species, even if these species individually rank low on an economic scale, may gain in ecological value and take on a higher overall ranking. Exceptions to this economically dependent ranking arise in the case of threatened or endangered species, for which ecological considerations legally outweigh economic demands. This exception aside, our scheme

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**FIGURE 2.**—Flow diagram showing a series of prioritized sequential questions and their required research actions. Beginning at step 5, management actions lead to the conservation, protection, restoration, or enhancement of the particular habitat of concern, and, therefore, the target species. As indicated by inclusion in the shaded box, management actions stimulate research actions aimed at evaluating the degree of habitat risk.
offers an objective way for management to weigh social and political demands against the biological constraints within which a fishery must operate. The essential habitats would be identified by scientific research, and managers would have that information within a framework for debating the protection of a particular area.

If no essential habitat is identified for the species of interest, management is not restricted by habitat considerations unless the overlay of other species' habitat-life history matrices indicate a reliance on a habitat by other commercially, recreationally, or ecologically significant animals. We anticipate that as biological databases expand and are incorporated into interactive geographic information systems, it will be possible to relate biological understanding of a species' requirements for sustained production to social and economic demands that now often override the biological constraints on unrestricted resource harvesting.

Acknowledgments

This document evolved from discussions by the ad hoc Fisheries Resources Working Group at a Gulf of Maine Habitat Workshop. Members of the working group who are not authors are: Richard Cooper, Linda Deegan, Lewis Flagg, Don Gordon, John Nelson, Dave Schneider, and Dianne Stephan. Their contribution to this effort is graciously acknowledged. The workshop was hosted by the Regional Association for Research in the Gulf of Maine and was funded by the Regional Marine Research Board and by the National Undersea Research Center at the University of Connecticut. The manuscript was much improved by the suggestions of two anonymous reviewers and the editorial staff of this journal.

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