A Conceptual Model of the Impacts of Fishing Gear on the Integrity of Fish Habitats

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Abstract: *Fishing gear is used over large regions of continental shelves worldwide, but studies of the effects of fishing on seafloor habitats are generally conducted on a limited number of sediment types, making the wider application of particular studies difficult. Fishing gear can reduce habitat complexity by smoothing bedforms, removing emergent epifauna, and removing species that produce structures such as burrows. I developed a conceptual model of gear impacts across gradients of habitat complexity and levels of fishing effort to provide a more holistic understanding of the effects of fishing gear. Each habitat type, in an unaffected state, was categorized and scored numerically based on the components of habitat structure. Values for highly affected habitats, based on observations, were integrated into the model and represented the most affected state. The model predicts linear reductions in complexity based on linear increases in fishing effort. For example, the complexity value of pebble-cobble with emergent epifauna decreases linearly to half the unaffected value (i.e., 10 to 5) in the most affected condition. Research is needed to refine the model and develop improved predictive capabilities. For example, threshold effects may occur that depend on habitat type, fishing gear, and fishing effort. Adding feedback loops to the model, based on recovery rates of habitats, will greatly increase the value of such models to managers. The model can be used directly for management in the current iteration by adopting a well-conceived adaptive management strategy. The objective of such an approach must include both the sustainable harvest of fishes and the maintenance of biodiversity.*

Modelo Conceptual de los Impactos de Artes de Pesca en la Integridad de Hábitats de Peces

Resumen: *Los equipos de pesca han sido usados en grandes regiones de la plataforma continental a nivel mundial, pero los estudios de los efectos de la pesca en hábitats del lecho marino han sido conducidos generalmente a un número limitado de tipos de sedimento haciendo que la aplicación amplia de estudios particulares sea difícil. Las artes de pesca pueden reducir la complejidad del hábitat al suavizar formas de lecho rocoso, removiendo la epifauna emergente y removiendo especies que producen estructuras como son las madrigueras. Desarrollé un modelo conceptual de impacto de artes de pesca a lo largo de gradientes de complejidad de hábitat y niveles de esfuerzo pesquero para proveer un entendimiento más completo de los efectos de las artes de pesca. Cada tipo de hábitat en un estado de no afectación fue categorizado y catalogado numéricamente en base a los componentes de la estructura de hábitat. Valores altos de hábitats altamente afectados basados en observaciones fueron integrados al modelo y representaron los estados más afectados. El modelo predice reducciones lineales en la complejidad en base a incrementos lineales en el esfuerzo pesquero. Por ejemplo, la complejidad del valor de guijarro-adoquín con epifauna emergente disminuye linealmente a la mitad del valor de no afectado (i.e., de 10 a 5) en las condiciones más afectadas. Se necesita investigación para refinar el modelo y desarrollar capacidades predictivas mejoradas. Por ejemplo, efectos límite pueden ocurrir dependiendo del tipo de hábitat, tipo de arte de pesca y esfuerzo pesquero. La adición de rutas de retroalimentación al modelo en base a tasas de recuperación de hábitats podría incrementar grandemente el valor de estos modelos para los manejadores. El modelo puede ser usado directamente para el manejo en su forma actual, adoptando una estrategia adaptable y bien concebida. El objetivo de este tipo de aproximación deberá incluir tanto la cosecha sustentable de peces, como el mantenimiento de la biodiversidad.*

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Introduction

Fishing gear is used over large regions of continental shelves worldwide (Watling & Norse, this issue). Studies on the effects of fishing gear are generally conducted on a limited number of sediment types because the focus of each study is on a particular fishery, gear type, or target species. Also, because different studies often have distinct scientific approaches and work on the problem from different perspectives, the comparability of results is difficult (Auster & Langton 1998). These differences impede our ability to conceptualize a more holistic understanding of the effects of fishing gear and lead managers to reject action in lieu of further study. I developed a conceptual impact model that encompasses a wide range of habitat types and focuses on the structural components of habitat that provide shelter for fishes.

It is axiomatic that coral reefs, kelp beds, and seagrass beds are managed for the maintenance of habitat integrity. The fishes and fisheries dependent on these habitats could not, in general, be sustainable without such structures (Heck & Orth 1980; Ebeling & Hixon 1991; Sale 1991). In these systems, linkages between habitat-level processes and population-community dynamics are relatively clear and have been the basis for research approaches for decades. When we move away from such charismatic, high-topography habitats, however, the connection between the fishes we harvest and physical habitat structure is much less clear. Perhaps this is due to the scale at which we generally study these different systems: on a small scale at the level of individual fishes for shallow, high-topography habitats and on a large scale at the population level for deep, low-topography systems (e.g., Auster 1988).

Habitat-mediated processes occur over a gradient of complexity. For example, coral reef fishes require specific structures; when those are removed, populations respond negatively. For species with facultative habitat associations (Auster et al. 1995, 1998), responses may be less direct. If habitat structure increases survivorship for only the juvenile life-history stage of a species, what range of effects are detectable in the dynamics of adult populations, and how would we separate these from random variation in mortality rates? Adult population level may also have an effect on the importance of habitat-related processes to population dynamics. At high population levels, when settling juveniles saturate habitats, habitat-mediated predation may not be detectable due to the high abundance of juvenile fish as prey. When numbers of spawning adults are low, however, habitat-mediated processes may be extremely important because habitats may not be saturated and survivorship may be directly related to habitat integrity (Lindholm et al. 1998). Damaged habitats may therefore impede the recovery of overexploited species by reducing the survivorship of early benthic phases of target taxa.

Our understanding of the distribution and components of habitat is limited. Wide continental shelves have generally been mapped by means of traditional grab samples, which give us the distribution of sediment types. Although sediment type is an integral descriptive term for habitat (e.g., mud, sand, cobble), direct observations using research submersibles and robotic vehicles have shown that sediment topography (e.g., bedforms produced by currents) and biogenic structures (e.g., burrows, sponges) produced by other animals provide "structure" with which fishes and other mobile fauna associate in order to obtain shelter from predators, ambush prey, and reduce energy needed to maintain position (Auster et al. 1995, 1998). Sediments are classified along a gradient of grain sizes, from mud to boulders. The various forms these can take, and the associations of infauna and epifauna with sediments, produce a wide diversity of habitat types for fishes and associated fauna. Auster et al. (1998) developed a hierarchical approach for classifying habitats on the temperate continental shelf of the northwest Atlantic. Eight general categories increase from simple to highly complex (Table 1). For example, epifauna in sand and mud provide shelter and enhance crypsis for concealment from predators. Waves and currents form sand wave fields that provide shelter from high current speeds, reducing the energy needed to maintain position on the bottom and permit ambush predation of drifting demersal zooplankton. Currents can sort loose sediments and deposit shells and cobbles in the troughs of sand waves; the small crevices provide an ephemeral habitat for small fishes and crustaceans. Cobble bottoms supply interstices for shelter sites but also furnish hard surfaces to which epibenthic organisms such as sponges and bryozoans can attach. These emergent epifauna provide additional shelter value. Scattered boulders also supply shelter from currents, but boulder piles provide deep crevices for shelter required by some species such as redfish (*Sebastes* spp.).

Model Description

The range of habitat values (categories 1–8), based on the hierarchy, is not linear throughout the range of values (Table 1). I assigned each category a numerical complexity score, based on the level of complexity. The complexity of categories 1 through 5 increase linearly. Category 6 is based on a score of 5 from the previous category plus 5 for dense emergent epifauna, which I assumed was equal in cover value to small interstices. Category 7 is based on the score of 10 for cobble and emergent epifauna plus 2 for shallow boulder crevices and current refuges. Finally, category 8 is scored as 15, based on the presence of shallow crevices and current refuges scored as 12, plus deep crevices scored as 3.

Table 1. Hierarchical classification of fish habitat types on the outer continental shelf of the temperate northwest Atlantic.*

Category	*Description*	*Rationale*	*Complexity score*
1	flat sand and mud	areas with no vertical structure such as depressions, ripples, or epifauna	1
2	sand waves	troughs provide shelter from current; previous observations indicate that species such as silver hake hold position on the downcurrent sides of sand waves and ambush drifting demersal zooplankton and shrimp	2
3	biogenic structures	burrows, depressions, cerianthid anenomes, hydroid patches; features that are created or used by mobile fauna for shelter	3
4	shell aggregates	provide complex interstitial spaces for shelter; also provide a complex, high-contrast background that may confuse visual predators	4
5	pebble-cobble	provide small interstitial spaces and may be equivalent in shelter value to shell aggregate, but less ephemeral than shell	5
6	pebble-cobble with sponge cover	attached fauna such as sponges provide additional spatial complexity for a wider range of size classes of mobile organisms	10
7	partially buried or dispersed boulders	partially buried boulders exhibit high vertical relief; dispersed boulders on cobble pavement provide simple crevices; the shelter value of this type of habitat may be less or greater than previous types based on the size class and behavior of associated species	12
8	piled boulders	provide deep interstitial spaces of variable sizes	15

**Classification is based on Auster et al. (1995), Langton et al. (1995), Auster et al. (1996), and unpublished observations.*

Fishing activity (e.g., trawls, dredges) reduces habitat complexity by smoothing bedforms (e.g., sand waves and ripples), removing emergent epifauna (e.g., sponges, worm tubes, amphipod tubes, mussels, hydroids, and anthozoans) and species that produce structures such as pits and burrows (e.g., crabs and fishes, Fig. 1; Auster et al. 1996). The conceptual model (Fig. 2) shows the response of the range of seafloor habitat types to increases in fishing effort. The range of fishing effort increases from left to right along the x axis: 0 indicates no anthropogenic impact, and 4 is the maximum effort required to produce the greatest possible change in habitat complexity. The numbers at present are dimensionless because of a lack of data on the effects of various gear types, at various levels of effort, over specific habitats. The y axis is a comparative index of habitat complexity. Each habitat type starts at the value of the habitat in an unaffected condition. The habitat categories are representative of the common types found across the northeastern continental shelf of the United States and are likely to be found on most other continental shelf areas of the world. The responses to different types of mobile fishing gear should be similar as well (Auster & Langton 1998).

The model shows a range of changes in habitat complexity based on the effects of fishing gear. It predicts reductions in the complexity provided by bedforms from direct smoothing by the gear. The complexity values for the end points for each habitat show the most-affected condition and are based on empirical observations. Biogenic structures are reduced by a number of mechanisms such as direct gear effects and the removal of organisms that produce structures (e.g., crabs that produce burrows). There are some habitats for which the model shows no significant reductions, such as gravel areas with high current velocities where there is little settlement of epifauna. Although mobile gear would overturn pebbles and cobbles and perhaps would have effects on burrowing species such as lobsters, the actual integrity of the habitat would not be reduced. The value of cobble pavements is greatly reduced when epifauna is removed, however, because biogenic structures provide additional cover. Gear can move boulders and still provide some measure of hydraulic complexity to the bottom by providing shelter from currents. Piles of boulders can be dispersed with large trawls, however, which reduces the cover value for crevice dwellers.

Conclusion

My conceptual model is meant to serve two purposes. First, it can be used by managers in an effort to invoke a precautionary approach to managing fish habitat (Auster

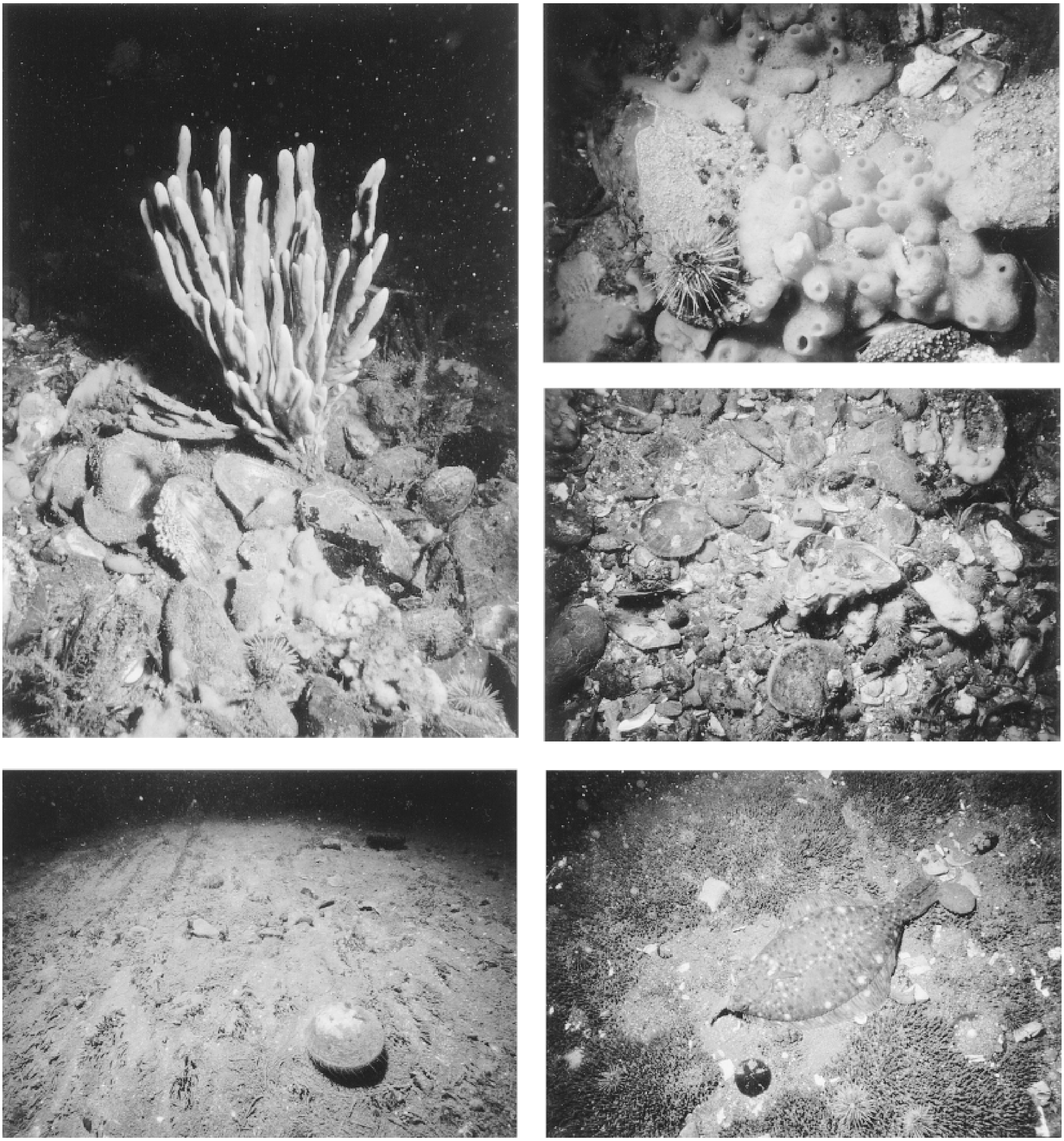

Figure 1. Examples of the effects of a single pass of a "rock rake" scallop dredge on unaffected seafloor habitats at Swans Island Conservation Zone, Gulf of Maine (clockwise from top left): cobble-shell bottom (first two pictures) (sponges "cement" shells and cobbles to form complex interstices and produce emergent structure); cobble-shell bottom after a single pass of a scallop dredge; sand bottom with emergent worm tubes; sand bottom after single pass of a scallop dredge.

et al. 1997) and as a basis for closing specific habitats to certain types of gear or invoking total closure based on values ascribed to particular habitats (Auster & Shackell 1997). Such regulations should be followed by careful monitoring to assess changes (e.g., recovery) in habitats and to determine if increases in juvenile survivorship occur. The second purpose in developing this model was to provide a basis to target future research in a more holistic approach. For example, the model shows a linear pattern in the decline of habitat complexity across a gra-

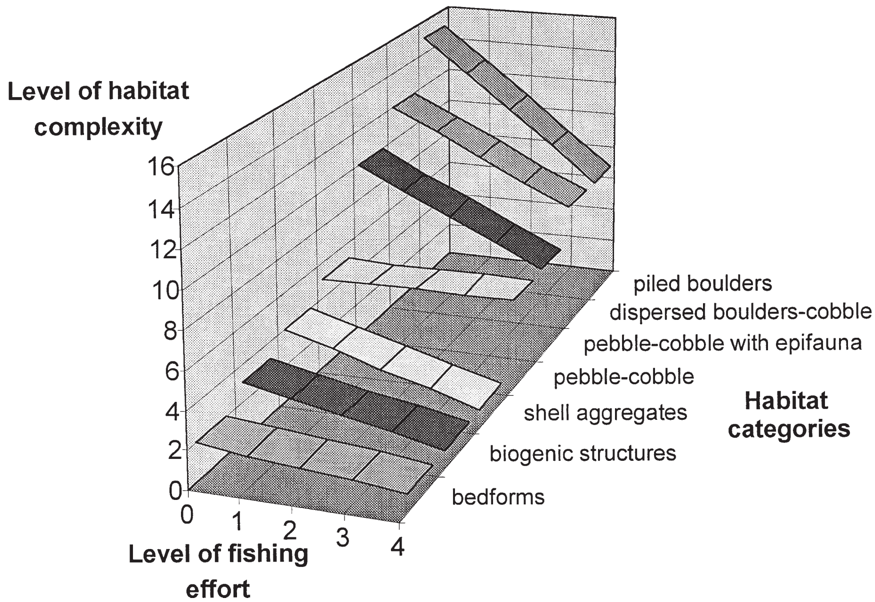

Figure 2. A conceptual model of the effects of fishing gear on sea floor habitat.

dient of effort within each habitat type. Although we know the end points for each habitat type, the decline in complexity may be nonlinear, such that there are threshold levels of effort that may produce large changes. In this case it will be necessary to partition the effects of fishing gear by type and level of effort. In addition, this simple model does not include feedback loops in the form of recovery time. Rates of recovery of habitat features, whether bedform features or benthic species, will be based on both the temporal pattern of natural processes and the timing and intensity of fishing effort. The ability to make predictions regarding these interactions will be critical for environmental and fisheries managers to more strategically manage fishing effort.

Only with a well-conceived adaptive management strategy can a habitat conservation approach be instituted with a minimal amount of social and economic dislocation to the fishing community. The objective of this approach must include both sustainable harvests of fishes and the maintenance of biodiversity.

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