Bioeconomic Modeling and the Management of Cold-Water Coral Resources

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Colony of *Lophelia pertusa* coral at Tisler reef, here heavily overgrown by the poriferan *Mycale lingua*, an indication of suboptimal growth conditions. Numerous small squat lobsters (*Munidopsis serricornis*) can be seen among the coral branches. *Photo courtesy of Tomas Lundälv, University of Gothenburg, Center for Underwater Documentation*

ABSTRACT. In the HERMES project, bioeconomic modeling is an integral part of the analysis of ocean hotspot management. This type of research is not commonly included in large, natural science projects. However, it is increasingly being shown that managing our common natural heritage requires an understanding not only of nature but also of human behavior and its interaction with nature. Bioeconomic analysis attempts to combine biological models with human behavioral models based on economic incentive mechanisms. Bioeconomic research in the HERMES project was used to inform management of one ocean hotspot: cold-water coral.

WHAT IS BIOECONOMIC MODELING?

Bioeconomic modeling combines ecological and economic models to analyze human interaction with nature (Figure 1). The basis of a bioeconomic model is usually a biomass or lumped parameter model describing the biology of one single population of a commercially important species. Though these simple models are the norm in bioeconomic modeling, more refined cohort models and interacting species are also studied.

Human interaction with nature is usually measured in terms of harvest of, or destructive effect upon, one or more stocks of the exploited species under study. The harvest is converted into revenues and costs by introducing market prices and costs, respectively. Nonmarket values, such as the value humans place on the pure existence of a natural resource, have also been included in bioeconomic models (Skonhoft and Johannesen, 2000). It is assumed that human behavior is driven by costs, revenues, and valuations of outcomes, together with, in some cases, measures regulating activity. In other words, profits or losses motivate behavior within the framework of management, but there may also be other motivations for choices, such as the value of the species' existence.

Economists are preoccupied with maximizing the utility of scarce resources, both natural and manmade. This utility can be measured in many different ways, depending on the objective of the natural resource manager. Usually, the objective would be to maximize economic value in the form of profits from a natural resource (i.e., securing maximum

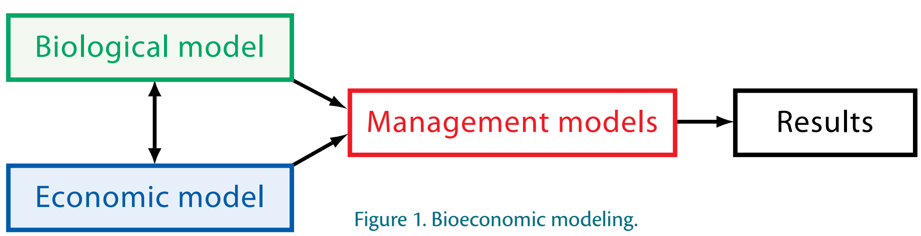

Figure 1. Bioeconomic modeling.

economic yield). Alternatively, maximizing food supply would involve maximizing the physical yield or sustainable harvest from a resource (i.e., ensuring maximum sustainable yield). In some cases, the focus may be upon maximizing employment (i.e., securing livelihoods). This concept would involve allowing unrestricted entry to a fishery, or allowing so-called open access to the fish resource. These three management objectives, which are not necessarily exclusive, are central to the foundation of bioeconomic theory, though an array of other intermediate management forms are also present in the literature (Homans and Wilen, 1997, 2005).

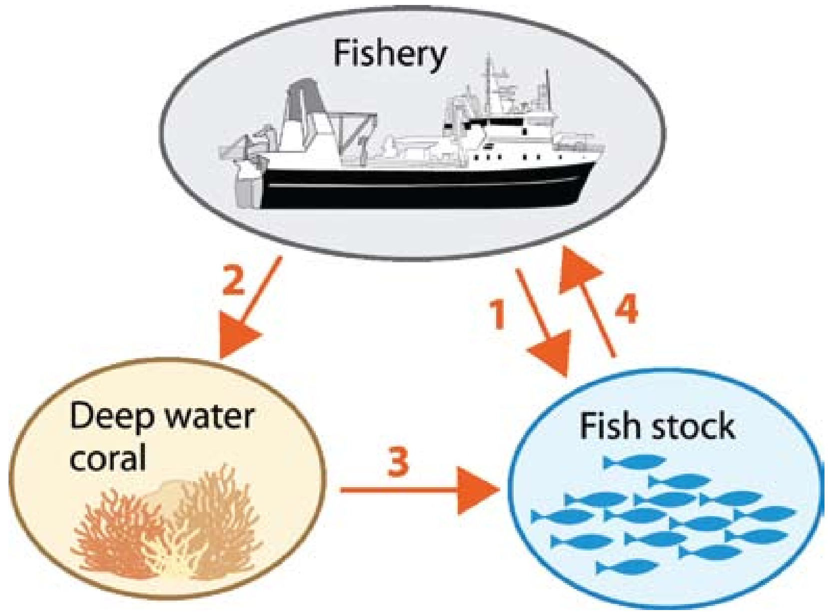

Figure 2. Fisheries interactions with cold-water coral resources—presence of externalities. (1) Fishing activity affects the fish stock. (2) Fishing affects the cold-water coral negatively. (3) The destruction of cold-water coral affects the fish stock, which again (4) affects the fishery.

Most work in bioeconomics has focused on single-species models, that is, how to manage a single stock in a given environment. In reality, species are not islands—they interact with other species and live in different habitats. The bioeconomic field has therefore expanded to multispecies models. These models clearly show the need for economics to help make the management decisions that may imply trade-offs among species. In other words, once you allow for the more realistic interaction of species, you need some way to value the species relative to each other in order to determine the optimal management approach. For instance, if you have a high-value predator species and low-value prey species, you should optimally manage the resource such that there is little harvest of the prey, in order to leave the prey as food for the larger predator stock, thus allowing a higher sustainable harvest. This approach has been applied to managing high-value cod and low-value capelin in Norwegian fisheries. Alternatively, if the prey is the valuable species, then it might even pay to subsidize the fishery of the predator, in order to keep the predator stock low and allow a larger prey stock to become available for harvest. This kind of subsidization has been carried out in many countries, such as Canada, Norway, and Namibia, by encouraging the harvest of marine mammals in order to obtain greater yield of commercially interesting prey species. In other countries, non-use values play a role in the valuation of such interacting species, encouraging management to secure minimum populations of marine mammals.

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HOW CAN BIOECONOMICS ASSIST IN THE MANAGEMENT OF COLD-WATER CORAL?

In the case of cold-water coral, there may be at least two types of values: use and non-use. Species, ecosystems, or habitats, such as cold-water coral reefs, may have pure existence values for human beings (i.e., the general public may value the simple existence of beautiful cold-water coral reefs, despite the fact that they may never actually observe, or make use of, cold-water coral themselves). Such non-use values can be observed from the fact that people contribute money and time to the activities of conservation groups in order to protect nature and natural environments that they never expect to use, see, or experience in situ.

Additionally, cold-water coral may have ecosystem values through being preferred or essential habitat for commercially interesting species (deepwater fish/crab) or their prey. The loss of cold-water coral would subsequently reduce the revenues emanating from the harvest of such species. In this context, one can think of coral as contributing to the growth of the fish species, so-called commensalistic interaction[1]. In this setting, a fishery with commensalistic interaction with a habitat reaps advantages from the existence of such habitats. And yet we often observe fishing activity having detrimental effects upon the very habitats that yield positive returns. A key example of this negative impact is bottom trawling in cold-water-coral areas. Bottom trawling is known to be highly destructive to cold-water coral reefs, which again can have a recursively negative effect upon both the trawl fishery itself and fisheries that use other gear types (see Figure 2).

Economists call this type of interaction an "externality"—one agent affects another's utility without the former having to take this effect into account. A classic example of an externality is when a company pollutes a community's environment without having to somehow correct this behavior or compensate the community. Economic theory shows that when such externalities exist, the market cannot be left to itself (i.e., the agents are unable to secure optimal behavior on their own, and some form of management is imperative).

> "BIOECONOMIC RESEARCH IN THE HERMES PROJECT WAS USED TO INFORM MANAGEMENT OF ONE OCEAN HOTSPOT: COLD-WATER CORAL."

If management is not imposed and enforced, we observe what has been coined the "tragedy of the commons" (Hardin, 1968). This "tragedy" has been used to describe the historically open-access nature of most fisheries worldwide. The externality here is the effect one fisherman has on another through the reduction of the fish stock. When there is no limit on access to the fisheries, there will be entrance into fisheries until all supernormal profits that the fish resource supplies are dissipated. This situation is usually described as fish stocks that are lower than that which gives maximum sustainable yield and maximum economic yield—when both biological and economic overfishing occurs. In recent years, many countries have started to tackle this issue by limiting entrance into fisheries and/or implementing other management measures in order to increase the biological and economic yield from the fisheries, and therefore correct the externalities. Nonetheless, the tragedy of the externality of habitat destruction, such as bottom trawling, is seldom taken into account in management. Habitats are rarely included in stock assessment (Armstrong and Falk-Petersen, 2008) other than indirectly through environmental changes. This situation means we have a tragedy of the common habitats—in this case, common cold-water coral reefs—that requires management to explicitly address the effects of fishing on the habitats.

HOW DOES BIOECONOMIC MODELING CONTRIBUTE TO OUR KNOWLEDGE OF COLD-WATER CORAL MANAGEMENT?

In the HERMES project, we used different fisheries-habitat models as well as management forms to analyze the bioeconomic interactions between fishing activity and cold-water coral.

In a bioeconomic model setting, we treat the coral as one stock of species in a two-species interaction with a commercially harvested fish stock (Flaaten, 1988; Hannesson, 1983). The cold-water coral resource is assumed to be nonrenewable or only very slowly renewable, due to its very slow growth. We can then show how management choices can seriously affect the degree to which coral resources decline over time. As mentioned earlier, in an open-access fishery, fishing effort continues to enter into the equation as long as there are supernormal profits to be made. If this fishing effort, such as bottom trawling, also has a destructive effect upon what is for all intents and purposes a nonrenewable resource such as cold-water coral, unlimited access results in the coral being completely destroyed. This damage may happen even if the coral is a vital habitat for the

[1]A commensalistic interaction is an association in which one benefits and the other derives neither benefit nor harm.

commercial fish species being harvested, because the unmanaged nature of open access allows the agents involved to fish without taking any other effects into account (i.e., they may saw through the branch upon which they are sitting, because no fisherman has an incentive to reduce his or her destructive footprint). In traditional theory of open access, the fish stock is not fished to extinction because the cost of extracting the last fish is so high that commercial activity will terminate before that point. In the case of coral, however, there is no extra cost involved, and therefore the resource may be completely destroyed as a byproduct of the fishery. If the coral has a positive effect upon the fish stock, coral decline has a negative effect upon the fishery, reducing its harvest potential.

This situation has been observed in Norway, where cold-water coral reefs have provided important fishing grounds for stationary gear users, such as gill-netters and long-liners, who position their nets and baited lines near the reefs to yield higher catch rates (Mortensen et al., 2001). In the past, bottom trawlers avoided cold-water coral reefs for fear of damage to nets, making them de facto refuges for fish. Since the 1980s, however, larger vessels with heavy rock-hopper gear that rolls over and moves or crushes objects and organisms on the ocean floor have been encroaching on previously inaccessible areas, targeting the same species as stationary-gear users (Fossa et al., 2002). Stationary-gear users have since then been increasingly voicing their concern about the effects of bottom trawling as a contributing factor in their decreasing catch rates.

Figure 3 shows how, in a bioeconomic two-species model of open access, a nonrenewable habitat, such as a cold-water coral reef, develops over time, given a commensalistic interaction between the habitat and the fish stock, or no interaction at all. The habitat is depleted regardless of its role, although depletion is faster when the habitat and the fish stock interact. Because the fishery is open access, effort is attracted to the fishery without any concern for the habitat. If the habitat has a positive effect on the stock, the revenues are greater, which attracts more effort and thereby reduces the cold-water coral further.

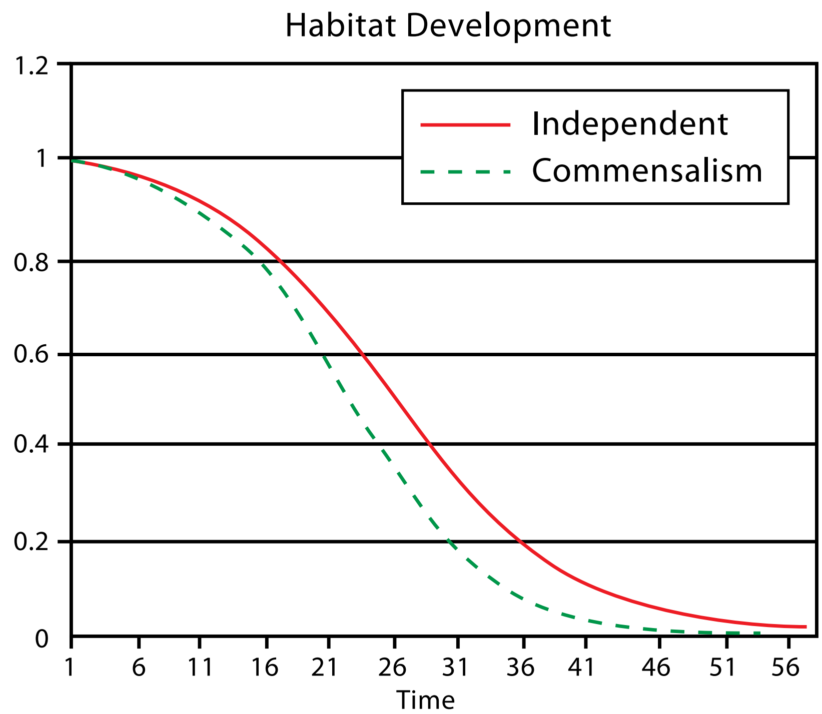

Figure 3. Quantity of nonrenewable habitat over time under open access fishing, dependent on whether there is commensalistic interaction between habitat and fish stock or not.

Managing the fish stock by limiting access in some way may still not be enough to secure the full potential of the fishery unless the interaction between the habitat and the fishery, and the effect of fishing upon the habitat, is taken into account. Only when management incorporates these interactions will the tragedy of the habitat commons be eliminated.

Not all fishing practices are equally destructive to cold-water coral. For instance, stationary gear, long lines, and gill nets have far-less-damaging effects on cold-water coral reefs than bottom trawling. Thus, it is of interest to study how to manage fisheries where there are more than just highly destructive fishing activities present.

We therefore employ a bioeconomic model with two gear types (Kahui and Armstrong, 2008), one habitat-destructive and one nondestructive, both harvesting a commercially interesting fish species. We model two habitat-fish interactions: (1) the habitat is preferred in some way by the fish, or (2) the habitat is essential to the fish species. In the first case, the coral can be seen to attract fish in some way (e.g, as nurseries or for protection of young), leading to a concentration of the fish and thereby reducing the cost of harvesting. In the second case, the habitat not only concentrates the fish, thereby reducing the cost of harvesting, but also positively affects the growth of the fish stock. We find that as long as the fishery is managed in an optimal fashion—here in the sense of maximizing profits of harvest—the type of interaction strongly affects how much coral destruction should be allowed through fishing activity. Some bottom trawling is usually allowed until an optimal level of fish and coral is reached. However, the optimal amount of coral and fish stock will depend very much on the parameters of the model and the type of habitat interaction. It must be noted that optimality in this study is limited to profit maximization, but once other values are included, such as existence values or ecosystem values, these results may be somewhat changed.

THE WAY FORWARD

The theoretical bioeconomic analysis of habitat-fisheries interactions described above highlights the need to learn more about these interactions. What kinds of interactions are there between commercially interesting species and different habitats? How important are specific habitats to the wellbeing of different species? Do different habitats play important roles in different parts of species' life cycles? What happens if specific habitats disappear or are greatly reduced? What other ecosystem services are supplied?

Theoretical bioeconomic analysis also underlines the need to act as a matter of urgency. The existing management mechanisms (or lack thereof) in many parts of the ocean today probably result in cold-water coral declining faster and to a greater degree than if habitat destruction were included as a factor in the regulation of fisheries. The 2006 United Nations General Assembly resolution 61/105 calls upon "*States to take action immediately…to sustainably manage fish stocks and protect vulnerable marine ecosystems, including seamounts, hydrothermal vents and cold water corals, from destructive fishing practices, recognizing the immense importance and value of deep sea ecosystems and the biodiversity they contain.*" This resolution is clearly a move in the right direction.

The application of a precautionary approach to the negative effects of human activities on habitat has led to increasing calls for the creation of area closures (Armstrong and van den Hove, 2008). Our research shows that, from a fisheries perspective, it would also be advantageous to increase our knowledge of fisheries-habitat interactions. In collaborative management efforts, the existence of fish-habitat interactions make it the collective interest of fishermen to control habitat-destructive fishing practices.

Biological research shows that cold-water coral habitats support high biodiversity. This species diversity is not static but changes from region to region: in some areas we find specific species connected with cold-water coral, while in other areas very different species may be more prevalent. This observation underlines the need to look at widely dispersed case studies of coral-fisheries interactions, not only due to these biological differences, but also because fisheries and management practices vary widely from one jurisdiction to another.

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