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Sustainability and economic consequences of creating marine protected areas in multispecies multiactivity context

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HIGHLIGHTS

- ▸ Impacts of marine reserves have been investigated in multispecies fishery.
- ▸ Prey species possesses heterogeneous intrinsic growth rate and is harvested.
- ▸ Creation of reserve prevents species extinction under exploitation.
- ▸ Protection reduces the economic rent from fishery.

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ABSTRACT

The present study deals with harvesting of prey species in the presence of predator in a multispecies marine fishery. The total habitat is divided into two patches: one is reserve area where fishing is completely banned and other zone is called fishing area where only prey is exploited. We assume that the prey fish possesses heterogeneous intrinsic growth rate with uniform carrying capacity where as predator has constant intrinsic growth rate with prey dependent carrying capacity. The analytical conditions are derived to prevent the species extinction for larger employed effort in single (only prey) species fishery. Optimal equilibrium *premium* are presented for both monospecies and multispecies fishery for all degree of protection. *Increasing standing stock* (*ISS*) and *protected standing stock* (*PSS*) are measured in the presence of prey–predator interaction.

1. Introduction

Significant numbers of marine organisms, including mammals, birds and turtles, as well as some commercially harvested fish and shellfish are now threatened or endangered. Conventional management tools such as taxation, license fees, lease of property rights, seasonal harvesting etc. have failed to provide any significant protection of these resources. Clearly, new management approaches or options must be considered to stem the damage and ensure that marine ecosystems and their unique features are protected and restored. As management becomes more integrated and holistic, marine protected areas (MPAs) will take on greater importance as a tools for conserving marine resources. Although, the protected area concept, with its emphasis on management of spaces rather than species, is not new and has been used frequently on land, until recently there have been less support and few interagency efforts to insight protected areas as a major marine management measure. MPA based approach will shift the focus from agency specific problem management to interagency cooperation for implementing marine politics that recognize the spatial heterogeneity of marine habitats and the need to preserve the structure of marine ecosystems.

Various achievements are expected from the creation of marine protected areas. The objectives pursued can usually be classified under one of the following three categories: ecosystem conservation, fisheries management and development of non-extractive recreational activities. Promoting fishery management goals and objectives may require different criteria for designing and implementing MPAs, than for protecting unique habitats or biological diversity. Lauck et al. (1998) asserted that MPAs can be viewed as a kind of insurance against scientific uncertainty, stock assessments, or regulation errors. Conrad (1999) showed that, in the absence of ecological uncertainty and in the context of optimal harvesting, reserve generates no economic benefits to the fisherman. His results coincides with the perspective of many fisherman and also some economists. Hannesson (1998) developed two deterministic equilibrium models, one is continuous and the

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other is discrete. The conservation effect of a marine reserve is shown to be critically dependent on the size of the marine and the migration rate of the fish. Sumaila (2002a,b) has shown that MPA can protect the discounted economic rent from the fishery if the habitat is likely to face a shock and fishermen have a high discount rate. He concluded that the total standing stock biomass increases with the increasing size of the MPAs, but only up to a point. Lubchenco et al., (2003) has focused on the multiple benefits of MPAs which include protection of habitats, conservation of biodiversity, protection or enhancement of ecosystem services, recovery of depleted stock, insurance against environmental uncertainty and recreation etc. Making use of a single-species multi-cohort model incorporating a stock recruitment relationship, Holland and Brazee (1996) have shown that marine reserves could improve sustainable catches in overexploited fisheries, given a fixed level of fishing effort. Recently, Kar and Matsuda (2008) examined the impact of the creation of marine protected areas (MPAs), from both economic and biological perspectives. In particular, they examined the effects of protected patches and harvesting on resource populations and concluded that protected patches are an effective means of conserving resource populations, even though extinction cannot be prevented in all cases. Kvamsdal and Sandal (2008) also examined the consequences of marine protected areas on both economic and biological perspectives. They observed that the protected area does not produce any economic benefit, but the biological stock level increases as the size of the protection increases.

Most management measures are directed at individual stocks of a single species and do not take into account species interactions, such as prey–predator relationships. A basic assumption of most models used to determine a catch level is that the catch rate a stock can sustain can be designed based upon the average productivity of the stock. Thus, maintaining the stock size that allows maximum sustainable yield (MSY) historically has been a major management goal. Fishing at the MSY level does not ensure constant catches in the future. Legovic et al. (2010) show that application of MSY policy will lead to extinction of a large number of fish species in most ecosystems. More precisely, they show: approaching MSY in ecosystems means that most likely fish species will be driven to extinction in every fishery that includes exploitation of at least one trophic level which is directly or indirectly used as food for a higher trophic level. Because such single and multispecies fisheries make up a great majority of existing fisheries, attempts to reach MSY should be discouraged instead of being legally prescribed as a goal. Recently, Kar and Misra (2006) consider a prey–predator system in a two patch environment: One accessible to both prey and predators and the other being a refuge for prey, and study the dynamics of the system. Baskett et al. (2007) highlight the importance of species interactions to reserve design and provide guidelines for how this complexity can begin to be incorporated into conservation planning. Kar and Chakraborty (2009) consider a prey–predator fishery model with prey dispersal in a two patch environment and their simulation outputs indicate that MPAs can substantially reduce the risk of fisheries collapse. Other possible benefits ranging from preservation of biodiversity and ecosystem integrity to increase tourism revenue in reserve zone are also considered. Boncoeur et al. (2002) considered a marine reserve in a multispecies, multi-activity context. This article investigates some economic consequences of creating a marine reserve on both fishing and ecotourism, when the range of controllability of fishing effort is limited and the impact of the reserve on ecosystem is taken into account.

Globally, there has been a surge of interest in designating areas of the seas as marine protected areas to maintain and conserve marine species and habitats threatened by human activities. There is growing consensus that living marine resources require more stringent protections. Better approaches for utilizing and protecting living marine resources are needed; however, choosing the best methods to maintain or restore the health of marine ecosystems is a difficult task for resource managers. Already, we have mentioned that conventional fishery management commonly focuses on single species. Whether or not these single species management strategies achieve their specific goals, their practice often neglects other important and pervasive problems. Furthermore, regulations designed for one fishery may negatively influence other species on the same fishing ground through prey–predator relationships (Legovic et al., 2010).

The main purpose of this study is to develop further insights into biological as well as economics of the marine reserves, from a multispecies perspective and taking into account the heterogeneous intrinsic growth rate for prey species. Though our model system is not based on a case study, however, krill–whale (or seal) community could be a good example for such a system. Inspite of having some other resources of food such as zooplankton, copepods, and squids etc. krill, which are small shrimp, is the main (also favorite) source of food for whales and seals. In fact, seals have a relatively small fed area and without krill in their immediate area, their food supply becomes limited. Also in our prey–predator system, while the former is targeted by commercial fishing, the latter is not subject to harvest, as it has competing market values associated with the nonconsumptive use such as for ecotourism purposes (whale and seal watching) (see Boncoeur et al., 2002; NRC, 2001). Tourists are willing to pay significant sums for whale-watching tour, mainly to experience whales in their natural environment. It is likely, in fact, that the market value of a whale-watching trip exceeds the market value associated with whale meat. Whales also have value through their ecological role in maintaining the natural abundance of other marine species, including commercially valuable fisheries. For the above reasons we have not considered the presence of alternative prey and harvesting of predator species. However, our results give some significant differences from the single species results with MPA. Our multispecies modeling approach is also supported by the previous investigations of Boncoeur et al. (2002) and Reithe (2006).

One of the controversial issues in designing MPAs is deciding where to put them. Kelleher (1999) identified several classes of related criteria that bear on choice of a site: biogeographic and ecological criteria; naturalness; economic, social and scientific importance; international or national significance; practically or feasibility; and duality or replication. However, these guidelines neither offer guidance on how to prioritize these criteria nor provide advice on how to rank candidate sites according to each criterion.

If conservation of biodiversity is the goal, then ecological reserves must be located in places that will offer protection to the full spectrum of the species and habitats. Crowder et al. (2000) modeled a system of sources and sinks for reef fish and found that at high fishing effort, placement of reserves in sink areas not only reduced the capacity of the reserve to support the fished population, but also concentrated fishing on source populations. The model suggests that displacement of fishing effort to source population could actually further the decline of fish stock. Therefore, when reserves are established to benefit particular fish stocks, the relative productivity of different areas should be considered. Schnier (2005a) analyzes how the heterogeneity in the intrinsic growth rates and carrying capacities influence the optimal bioeconomic marine reserve formation within a fishery. The primary findings of this research is that first and foremost, in the presence of heterogeneity in growth functions within a fishery, a positively size optimal marine reserve exist.

In the following Section 2, first we describe the main biological and technological assumptions of our model and then we construct the appropriate mathematical model. The condition of species