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Review

Marine Protected Areas: a Review on Their Benefits and Designs for Fisheries Management

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Abstract

This paper reviews selected economic literature on marine protected areas (MPAs) to examine the extent to which MPAs can effectively support fisheries management. The potential benefits of MPAs are discussed including increased catch and population and providing a hedge against management failure and economic approaches, mostly based on bioeconomic modelling, to MPA design for these benefits. In addition, a discussion on how the MPAs can enhance fisheries management by avoiding the dissipation of benefits and the risk of overexploitation under different management regimes is also provided.

Introduction

Even though the oceans occupy more than 70% of the earth's surface and 95% of the biosphere (National Research Council 2001), there is a growing concern for large negative impacts of heavy human use in different activities on the marine resources such as fishing, aquaculture farming and waste disposal, and excess nutrients from agricultural run-off. Marine habitats have undergone a substantial decline over the last few decades, most of which is attributable to fishing (Jackson 2001). The Food and Agriculture Organization (FAO) of the United Nations reports that around 77% of the world's marine fisheries are either fully exploited or overexploited (FAO 2006). Also, Myers and Worm (2003) estimated that predatory fish stocks have declined by more than 90% over the past 50 years. These declines have raised the growing perception that traditional management of marine resources which focuses on reducing efforts such as bag or size limits, quotas, gear restrictions and by-catch reduction is insufficient (National Research Council 2001).

Over the past century, new management approaches or options have been considered to ensure that marine ecosystems and unique habitats are protected and restored. In this regard, marine reserves or protected areas are proposed as tools to relieve stress on marine resources and ecosystems. The term 'Marine Protected Areas' (MPAs) covers a variety of possibilities from no-

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take areas to multiplied use areas. Often, MPAs are viewed as a complement to traditional management strategies.

According to Roberts et al. (2005), MPAs should be incorporated into modern fishery management because they can achieve many things that traditional tools cannot. Traditional management strategies rely heavily on the accurate assessment of the stock size, and biological and ecological parameters (life history, fishing mortality, and so on). However, scientific and technological limitations, as well as unpredictable natural fluctuations in these parameters, present significant challenges to traditional fisheries management strategies. Consequently, unintentional overexploitation of stocks can easily occur even when harvest rates are perceived to be low. Marine protected areas can safeguard against errors in fisheries assessment by providing protection to a portion of the stock (Lauck et al. 1998).

Application of MPAs has been controversial. Some fisheries scientists consider MPAs as unnecessary and ineffective (Shipp 2003; Allison et al. 1998). Others have asserted that total allowable catches (TACs), reducing catch or effort levels and gear limitations can gain the same effect as a MPA (Greenstreet et al. 2009; Conrad 1999). The existence of the different opinions has raised the need to investigate implication and effectiveness of MPAs with regard to the relevant economic and social issues.

Previous reviews discuss different perspectives of MPAs related to ecosystem preservation, fisheries management, distribution consequence of MPAs and methodological issues for economic valuation and cost benefit analysis of MPAs (Alban et al. 2006; Grafton et al. 2005). In this paper some useful information is provided through reviewing MPA literature that discuss the extent to which MPAs effectively support sustainable fisheries management which aims to restore and sustain marine ecosystems and foster the recovery of exploited species. The focus of this paper is to describe and analyse how MPAs can resolve open access fisheries, how the incentive based approach can be applied to support the implementation of MPAs, and how MPAs can play a role in the process of resource allocation among stakeholders after the establishment of MPAs. It is envisaged that the results of this paper will complement those of previous authors and provide knowledge which is necessary for designing comprehensive MPA networks.

Literature on MPAs is abundant and growing rapidly. Existing studies in this area often focus on two main issues: benefits of establishing MPAs and the design of MPAs. Although theory and evidence suggest that MPAs will benefit fishery management (Clark 1996; Lauck et al. 1998; Ward et al. 2001), studying how they will benefit and how to optimally design them is not always simple.

Potential benefits from the establishment of MPAs

Recent reviews and studies have listed a number of potential benefits that may result from the implementation and management of MPAs. To shed light on this issue, this section will highlight both ecological and economic literature which discuss the benefits associated with the creation of MPAs.

Increasing catch and population

Marine protected areas may reduce catches in the short term due to the decrease of the fishing areas, but in the long term, it is expected that MPAs will produce higher catches and population that are not immediately apparent. Monitoring results from 89 no-take marine reserves around the world have shown that, on average, fish density, biomass, size and diversity all increased within marine reserves (Halpern 2003; Lester et al. 2009). The increase in catch was also found outside the reserves in different countries some years after the reserves were established (Gell and Roberts 2003; McClanahan and Mangi 2000).

Insights into the MPA function came from theoretical research which also demonstrated their effects on catch and stock. In an earlier work, Polacheck (1990) demonstrates that MPAs can generate benefits through increasing yield per recruit due to the movement of fish from the MPA to the outside areas. Pezzey et al. (2000) and Sanchirico and Wilen (2001) examined theoretical models with the density-dependent growth and concluded that a protected area may increase the abundance of the population. In some cases, it may even raise the aggregate harvest in the exploited population if the system dispersal benefits to the remaining open areas are large relative to foregone harvest due to the establishment of the reserve. Sanchirico and Wilen (2001) emphasised that the fact that MPAs stabilise or increase fish populations inside their boundaries could provide a similar function outside the protected area if the spillover effect is significant. This, in turn, could reduce variations in aggregate catch levels or increase the long-run total catch.

The establishment of MPAs does not always result in increasing yield and population. Takashina et al. (2012) reported that the creation of MPAs can cause a decrease in the abundance of prey species in multispecies marine fishery if the MPAs are intended to protect only the predatory species. The increase in yield and population with the creation of MPAs thus depends on a range of conditions. Most of the existing research on MPAs has dealt with this issue. Hannesson (1998) and Holland and Brazee (1996) have suggested that a reasonably sized MPA may increase yields in fisheries, but that little if any yield increases can be achieved in fisheries where effort is already at the level that produces maximum sustainable yield or maximum yield per recruit.

A protected area may also raise harvests and revenues if the fishing efforts were very high prior to the establishment of the reserve (Holland 2000; Gerber et al. 2003), although this could also be accomplished via more direct controls on fishing efforts or harvesting. In addition, fishing intensities are closely linked to benefits from protected areas. In terms of catch, MPAs tend to increase catches at high fishing intensities and decrease them under light fishing regime (Roberts and Sargant 2002). Catch may also increase with the MPA for both single species system (Bensenane et al. 2013) and multispecies system (Kar and Ghosh 2013).

Marine protected areas present a way to maintain fish populations and potentially enhance fish yields. As fish stocks begin to decline due to heavy fishing, management based on MPAs may protect fish species within MPA boundaries and provide a long-term benefit for fisheries management. However, in addition to theoretical studies, there is a need for more studies, especially empirical ones, to explore more empirical evidence related to this issue.

Hedging against uncertainty

Uncertainty is caused mainly by environmental fluctuation; however, it may also arise from the economic system, social components or institutional aspects (Flaaten et al. 1998; Sumaila 1998). By incorporating uncertainty into the model, many authors have concluded that MPAs are an effective insurance policy even if other management measures fail. Decreasing harvest rate without a protected area is not sufficient to prevent extinction if the uncertainty is great enough (Lauck et al. 1998). Therefore establishing MPAs may help to make fisheries less sensitive to uncertainty and help to hedge errors and bias in fisheries management.

Doyen and Bene (2003) examined the relationship between uncertainty and MPAs and showed that protected areas can simultaneously increase population persistence and raise the guaranteed harvest when there is uncertainty. Grafton et al. (2004) also demonstrated that an MPA size greater than zero, even a small size, can generate a higher discounted net return from fishing than no protected area in the presence of unexpected negative shocks. Their result is significant because it proves that MPAs can offer a hedge against uncertainty which neither input nor output controls can.

Far from providing a tool to hedge against uncertainty for the environment, MPAs are also expected to provide an insurance policy against management failures resulting from insufficient knowledge and understanding of the fishery system being managed. They may also provide an insurance policy in the case if there have been a lack of resources or political will to implement and enforce restrictions on effort or catch (Clark 1996; Sumaila 1998).

Improving fishery management

Traditional fishery management tools in general focus on input or output control. Effective application of these tools requires a high level of both biological and fishery information. As a result, insufficiency and uncertainties in this information can lead to failures in fisheries management (Botsford et al. 1997). The implementation of MPAs as a management tool in this context may reduce the need to obtain this information and, also provide some protections against failures and a precautionary approach to fishery management (Clark 1996; Lauck et al. 1998).

When striving to improve management effectiveness, fisheries scientists and managers face difficulties due to a lack of areas that are free from the effects of fishing in which to make assessments related to the impacts of gears on habitat destruction, compare fished and unfished areas, and compare areas before and after the onset of fishing. The creation of MPAs may provide the important reference sites needed for such experimental studies (Ward et al. 2001). Fishery management also requires information about stock assessment and population parameters of the growth and natural mortality to develop management models. If all areas are subjected to fishing, measuring these parameters is difficult (Ward et al. 2001). From this perspective, MPAs can benefit fisheries through allowing some populations and fishery parameters to be estimated independent of fishery influences.

Other benefits

Beyond the above benefits, some authors have discussed several other potential benefits. These benefits include opportunities for basic research and education, creating size for recreation, and diversifying the economy by providing new social and economic opportunities (Bohnsack 1998); increasing employment and improving livelihoods of coastal communities especially in developing countries (Ward et al. 2001;Reithe et al. 2014); increasing market value of a fishery by changing the composition of the catch (Sanchirico et al. 2002); successfully establishing ecotourism in protected areas (Boncoeur et al. 2002; Lee and Iwasa 2014) and controlling the by-catch of non-targeted species for different cases of ecological interactions between the targeted and the non-targeted species (Reithe 2006). All of these studies clarify various contributions of MPAs to fisheries management and social development.

Design of MPAs

Potential benefits of MPAs can only be attained when they are designed appropriately based on the goals of management. Improperly designed MPAs may result in more costs than benefits, and future support for MPAs in those regions will decline. Even if overall benefits of an MPA exceed the costs, certain groups or individual are likely to suffer or at least perceive that MPAs result in harm.

Different approaches to MPA design

There are two different goals in the establishment of MPAs: preserving biodiversity and managing fisheries to produce the sustainable large catches. Many authors consider that, in order to obtain potential benefits from protected areas, policy makers must be very clear as to what the MPAs are intended to achieve, and must incorporate these objectives into the design of the protected areas (Hastings and Botsford (2003); Botsford et al. 2003: National Research Council 2001). The location, size and shape of the protected areas must be determined to reflect the realities and the objectives of the areas to be protected (Sumaila 1998). For example, if marine biodiversity enhancement is the objective, a significant number of representative habitats must be set aside. By contrast, if fishery enhancement is the goal, then perhaps MPAs should be sited so the amount of spillover is maximised (Grafton et al. 2005).

The combination of the above two objectives in the same system of MPAs is the concern of scientists and policy-makers (Botsford et al. 2003). By investigating the conflict of two different goals of the MPA networks and trying to find the best solutions for both in the same MPAs, Hastings and Botsford (2003) found that the two goals of fisheries and conservation may not really be in conflict if we recognise that the fisheries oriented approach may be used to argue for a larger set-aside area than purely conservation arguments could. To achieve the conservation benefits and minimise the yield losses to fisheries, the design and evaluation of MPAs need to be based on clear conservation and fisheries objectives, social and institutional ability, existing fisheries management action and the ability to monitor and evaluate success (Hilborn et al. 2005).

Economic and social issues related to MPA design

Economic analysis plays a major role in the design, implementation and evaluation of MPAs. Until now, most of the economic research on MPAs has applied bioeconomic modelling, that is, research based on single species biological models to assess the consequences of establishing MPAs under different management regimes (Sumaila et al. 1999). In addition to computing the catch and stock levels, these models employ maximum sustainable yield (MSY) or maximum present value of the economic rent to determine the optimal design for the MPAs (Kvamsdal and Sandal 2008). Regarding the optimal design of MPAs, Gerber et al (2003) state that the optimal size of marine reserves would ultimately be determined based on particular conservation needs and goals, quality and amount of critical habitat, levels of resource use, efficacy of other management tools, and characteristics of species or biological communities needing protection.

The questions of the optimal size of an MPA and the total area that should be protected have been widely discussed by biologists and economists. From the ecological perspective, Roberts (1997) suggested that MPAs with a size of 50% or more can provide particular benefits for heavily exploited fisheries. Lauck et al. (1998) found that a protected area may actually increase the guaranteed catch as it allows for a greater exploitation rate in the harvested area because of the assurance a reserve provides against management failure. Based on their simulations, a reserve needs to be 50% or more of a defined habitat to ensure population persistence.

Like ecologists, economists have also studied MPA design issues. Holland and Brazee (1996) used a deterministic framework and showed that the relative benefits of reserves depend on their effect on harvesting in exploited areas and the discount rate. In contrast with previous models, they determined the optimal reserve size by maximising the present value of the harvest instead of maximising the sustainable yields, and concluded that the optimal size of a MPA will vary with the level of effort. Higher effort levels require larger reserve sizes to achieve maximum value from the fishery. By applying a logistic growth model, Hannesson (1998) and Conrad (1999) also examined the optimum size of MPAs. Hannesson (1998) investigated the economic and conservation effects of MPAs on an open access fishery and concluded that little would be gained by implementing MPAs without applying some measures that constrain fishing capacity and effort. He also indicated that an MPA should be 70-80% of the whole area to achieve both yield and conservation effects. Conrad (1999) studied the optimum size of MPAs in both deterministic and stochastic models. In the deterministic model, an MPA reduces the present value of net revenues so, under optimal management, there would be no need for an MPA. In the stochastic model, a protected area ranging in size from 40 to 60% has the ability to lower variation in fishable biomass, but, for an MPA equal to or greater than 70% of original grounds, net revenue would be non positive and there would be no incentive to fish.

In contrast with Hannesson (1998) and Conrad (1999) who are critical about the creation of MPAs, Grafton and Kompass (2005) combine ecological uncertainty into a bioeconomic model and find that MPAs are beneficial even with harvesting that tries to maximise the net returns from fishing. By dealing with environmental uncertainty in the model, they state that their findings are noteworthy because they contradict the widely held views that, for MPAs to be beneficial to fishermen, the population must be overexploited (Pezzey et al. 2000), the MPA must be large (Anderson 2002) and that MPA and output controls are equivalent methods in terms of their effects on fishery yields (Botsford et al. 2003; Hastings and Botsford 2003).

Focusing on economic yield and consumer surplus, the question of how biological and economic parameters and reserve size may affect economic yield and consumer surplus in an open access fishery outside the MPA is discussed in the recent study of Flaaten and Mjølhus (2010). Generally, maximum economic yield cannot be realised, but consumer surplus is greater with a reserve than without. This paper also demonstrates that the assumptions regarding post reserve growth and migration used in some papers, including Hannesson (1998), implicitly implies a less productive stock post reserve than pre reserve. Thus, modelling assumptions should be carefully scrutinised before management policy is concluded on the basic of theoretical studies. Economic analyses on the design of MPAs may help the managers make appropriate decisions relevant to creation of the MPAs. However, it is increasingly clear that in addition to economic considerations, all stakeholders should be meaningfully involved in the planning and design phases to ensure the success of MPA (Sanchirico et al. 2002).

Social issues regarding to the implementation of MPAs also need to be mentioned here. The difference in goals and requirements of different marine users may also cause conflicts over the implementation process of protected areas. Sanchirico and Wilen (2001) state that not everyone supports the expansion of marine reserves, of course, and that fishermen have been among the most vocal skeptics. From fishermen's perspective, the establishment of marine reserves can reduce their initial harvests, increase costs and restrict the area in which they can fish (National Research Council 2001). However, from the conservationists' point of view those who advocate MPAs, the benefits that MPAs provide for marine biodiversity through protection are numerous, and therefore there is an increasing need for areas to be protected. They believe that it is necessary to change fisheries management because of the depletion of many exploitable marine species (Ward et al. 2001).

Marine protected areas - How they can enhance fisheries management

Open access and marine protected areas

The majority of global fisheries are managed under regulated open access conditions (National Research Council 2001). An open access regime is one in which there is no legally defined ownership and every agent is free to exploit the resource. The theory of open access exploitation was first developed by Gordon (1954) and the most significant conclusion of this study is that the open access system is socially wasteful since the resource rents will be dissipated by over-capacity and excessive application of inputs. The management of fisheries, therefore, has progressed over the past century with the dual objectives of focusing on how best to optimally use a resource from an economic perspective and how to create a structure which provides a persistent and stable population over time from an ecological perspective.

Solutions to the problems of open access are often to create fishing rights, tradable quota and effort control in order to address the lack of property rights and management regulations. These management approaches, however, seem to fail to manage fisheries sustainably (National Research Council 2001). Marine protected areas as an ecosystem-based approach have been advocated as an alternative, with the aim of restoring and sustaining biodiversity and fisheries resources. More research also sought to evaluate if MPAs are superior to conventional management methods.

From a theoretical perspective, Hannesson (1998), Conrad (1999) and Anderson (2002) investigated how the problem of open access can be solved by the creation of MPAs. Their findings questioned the effectiveness of marine reserves or protected areas to address conservation problems. The open access system can lead to concentration of the fishing effort at the boundaries of MPAs and will eventually wipe out the MPAs' fishery benefits. They concluded that MPAs need to be used in combination with effort controls and/or other management measures to avoid the dissipation of benefits and the risk of overexploitation.

Ngoc et al (2009) studied the impact of MPA on the open access fisheries outside the MPA in NhaTrang Bay and investigated whether the protected area could contribute to fisheries management and what conditions and tools should be applied. The empirical analysis of trawlers operating around the NhaTrang Bay MPA, Vietnam demonstrates that open access outside the MPA can lead to overfishing. The abundance of the fish stock inside the MPA does not increase and even tends to decline in some areas after 3 years of establishment. This result demonstrated the occurrence of overfishing in the Nha Trang Bay MPA. The technical efficiency of the trawlers operating around the MPAs is relatively high, which can raise the catches and incomes of fishermen in the short term. However, the paper suggested that, without a feasible management regime, in the long run, this increased technical efficiency will increase the catch in open access fisheries and put a strain on fish stock capacity, thus diminishing the numbers.

Incentive-based approach and marine protected areas

Protected areas can promote resilience to shocks and raise profitability even when harvesting is optimal (Grafton et al. 2005). Despite these benefits, reserves cannot address all problems in fisheries, nor do they provide fishermen with incentives to act more responsibly in terms of their harvesting practices. Consequently, there is a need for management. Such management has usually been in the form of controls ranging from incentives to command-based approaches. Incentive-based approaches include economic instruments that can reward fishermen for sustainable practices and provide motivation to reduce or eliminate overcapacity and overharvesting.

Experience from the creation of protected areas has indicated that it may affect fishermen's economic status, and as a result it may change their behaviour. Marine protected areas impose additional costs on fishermen's operations directly (e.g. by limiting fishing ground), or costs are imposed indirectly through a new set of incentives created (e.g. displacement of fishermen from protected areas has an impact on other fishermen already operating in the areas to which the displaced fishermen relocate). The effect of MPAs on the fishermen's operational costs may change the fishermen's behaviour and, in turn, may influence the costs to the industry and reduce the effectiveness of management when the expected outcomes are not achieved. To solve this problem, the provision of incentives for fishermen using economic instruments should be considered and implemented.

Incentive payments aimed to compensate fishermen due to the loss of fishing ground may play an important role in achieving the expected outcomes of managers and society, depending on the type of incentives. As with fisheries management, incentive payments may change the behaviour of fishermen and provide them with motivation to fish sustainably. Hannesson (2000) has argued that, without changes to the incentives faced by fishermen that lead to overcapitalisation and rent dissipation under open access, no economic or conservation goals can be achieved from the creation of MPAs.

The incentive-based approach is discussed by Ngoc (2010), where the manager provides a payment for fishermen in exchange for operating within a conservation framework. By setting appropriate payments, Ngoc (2010) shows that the manager may preserve biodiversity, attain maximum social welfare and reduce the effort of open access fishermen who always attempt to get maximum profit or income. This can be done since the fishermen have to face the trade-off between increasing effort and decreasing payment received, which in turn may affect their net income.

Allocation of fishery resources and marine protected areas

The potential conflicts and interactions between different marine sectors are increasing over time; conflicts arising from the fisheries, aquaculture and tourism sectors, and between recreational and commercial fisheries, are particularly pressing. The most common conflict in these cases is the conflict over physical occupation of the ocean for the activities of the different stakeholders. As aquaculture occupies more space, the stock available for fishing may be smaller. This can lead to increases in the cost of fishing. On the other hand, the cost of aquaculture might also increase as more areas are allocated for wild harvest (Hoagland 2003).

The same conflict also arises between recreational and commercial fisheries, particularly under open access control. The lack of property rights or appropriate management strategies may lead to one of the two sectors leaving the fishery or never entering it due to the negative net benefit (Ngoc and Flaaten 2010). In order to prevent this happening, resources can be allocated for the two sectors via traditional management tools such as license fees or bag limits for recreational fisheries and tax or quotas for commercial fisheries. The reality shows, however, that the conflict may still remain if different management regimes are applied to manage the two sectors. Marine spatial planning may become an appropriate tool by providing a means of managing the potential conflicts. Protected areas are tools that are used in spatial planning management, and which may help to alleviate problems related to resource allocation between competing sectors. Protected areas not only define the operation area for each sector, but they may also help to improve catch and the fish stock by decreasing conflicts. Therefore, the assessment of the potential of protected areas for resolving conflicts should include consideration of fishermen's behaviour, particularly in terms of spatial harvest allocation, and the impact that one sector may be having on another. Fisheries' bioeconomic models, which contain both a spatial component and issues relating to the relevant sectors involved in the fishery, will need to be developed.

Conclusion

This paper reviews selected literature dedicated to benefits and optimum design of MPAs. It provides a context for understanding the role of MPAs in enhancing fisheries management. Despite the advantages of MPAs compared to traditional management tools, some concerns have been expressed about the effectiveness of the creation of MPAs when there are links between MPAs and outside areas as a result of the dispersal process. The question of how MPAs can help to solve the problem of open access fisheries, allocation of marine resources and resolving conflict between stakeholders should be considered to ensure the success of the MPAs.

When added to other management methods and regulations, MPAs can contribute to fisheries management by protecting the stock and helping to achieve sustainability in marine fisheries. The use of MPAs as a part of the strategy of sustainable fisheries management still needs more research and investigation.

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