Essays on the Economics of Marine Protected Areas and Fisheries Management

Quach Thi Khanh Ngoc

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UNIVERSITY OF TROMSØ
Norwegian College of Fishery Science
Department of Economics and Management

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Content

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List of papers

Paper 1:

Quach Thi Khanh Ngoc, Ola Flaaten, Nguyen Thi Kim Anh (2009). Efficiency of Fishing Vessels Affected by a Marine Protected Area – The Case of Small-Scale Trawlers and The Marine Protected Area in Nha Trang Bay, Vietnam. *Integrated Coastal Zone Management*, chapter 15. Wiley-Blackwell, US.

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Paper 2:

Quach Thi Khanh Ngoc (2009). Creation of Marine Reserves and Incentives for Biodiversity Conservation. Accepted into *Natural Resource Modeling*.

Paper 3:

Quach Thi Khanh Ngoc and Ola Flaaten (2009). Protected Areas for Conflict Resolution and Management of Recreational and Commercial Fisheries. Submitted to *Marine Resource Economics.*

Introduction

1. Background

Even though the oceans occupy more than 70% of the earth's surface and 95% of the biosphere (National Research Council, 2001), there is growing concern about large negative impacts of heavy human use in different activities such as fishing, aquaculture farming and waste disposal, excess nutrients from agricultural run off, and so on, on the marine resources. 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: p. 29). 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, there have increasingly been considered new management approaches or options 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 stresses on marine resources and ecosystems. Consequently, approximately 2.35 million km^2, equivalent to 0.65%, of the world's oceans are currently protected, and over the last two decades, the marine area protected globally has grown by approximately 5% per year (Wood, 2007).

The term ‘marine protected areas’ (MPAs) covers a variety of possibilities from no-take areas to multiplied use areas. Often, MPAs are viewed as a complement to traditional management strategies. According to Roberts *et al*. (2005), marine protected areas 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, make this virtually impossible. Consequently, unintentional overexploitation of stocks can easily occur even when harvest rates are perceived to be low. MPAs can safeguard against errors in fisheries assessment by providing protection to a portion of the stock (Lauck *et al*., 1998). The establishment of MPAs can protect fish stock and contribute to a reduction in the fishing mortality of adults, allowing the stock to replenish itself. While traditional management tools such as the reduction of the total allowable catch can achieve the same goal, protection of stock through the establishment of MPAs may be more easily enforceable (Pezzey *et al*., 2000).

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. If the open access regime is applied outside the MPAs, it can attract more fishermen to exploit benefits resulting from the migration process and this can reduce the effectiveness of the MPAs. The problem, thus, to be analysed in this thesis is how MPAs can benefit for fisheries management, and the conditions under which they are beneficial. Two papers address this question within a theoretical framework while one paper provides an empirical analysis of the efficiency of fishing vessels, examining the case of small-scale trawlers and MPAs in Nha Trang, Vietnam.

2. Literature review

Literature on MPAs is abundant and growing rapidly. Existing studies in this area often focus on two main issues: benefits from establishing MPAs and the design of MPAs. Although theory and evidence suggest that MPAs will benefit fishery management, studying how they will benefit and how to optimally design them is not always simple.

2.1 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. In the scope of this section, we only describe some of these benefits.

Increasing catch and population

MPAs may reduce catches in the short term due to decreasing the fishing areas, but in the long term, it is expected that MPAs will produce higher catches that are not immediately apparent. In an early work, Polacheck (1990) proves that MPAs can generate benefits through increasing yield per recruit and also help prevent recruitment overfishing. Pezzey *et al*. (2000) and Sanchirico & Wilen (2001) examine theoretical models with the density-dependent growth and conclude that a protected area may increase the abundance of the population and even in some cases may raise the aggregate harvest in the exploited population. In addition, Sanchirico & Wilen (2001) emphasise 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.

Establishment of MPAs does not always result in increasing yield and population but instead it depends on a range of conditions. Most of the existing research on MPAs has dealt with this problem. 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 maximise 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 and 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 protected areas benefits. In term of catch, MPAs tend to increase catches at high intensities and decrease them when fishing is light (Roberts & Sargant, 2002).

Although benefits from MPAs for increasing the catch and population depend on the certain conditions, networks of MPAs present a way to maintain fish populations and potentially enhance fish yields. As fish stocks begin to decline due to heavily 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 still need more studies, especially empirical studies, 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) examine the relationship between uncertainty and MPAs and show that protected areas can simultaneously increase population persistence and raise the guaranteed harvest when there is uncertainty. Grafton *et al*. (2004) also demonstrate 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 willingness 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 the fishery management (Clark, 1996; Lauck *et al.*, 1998).

When striving to improve the management effectiveness, fisheries scientists and managers face a difficulty 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, stabilising the economy (Bohnsack, 1998); increasing employment and improving of livelihoods of coastal communities (Ward *et al.,* 2001); increasing market value of a fishery by changing the composition of the catch . (Sanchirico *et al.*, 2002); 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 results clarify various contributions of MPAs to the fisheries management and social development.

2.2 Design of MPAs

Potential benefits from MPAs can be only 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, including stock size, and managing fisheries to produce the largest 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. The location, size and shape of the protected areas must be decided to reflect the realities as well as 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 recent concern of scientists and policy-makers. 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).

Meeting the goals of both fisheries and conservation in the same MPA is not an easy task and can sometimes be even more costly. However, a reasonable MPA design that satisfies both objectives may improve the effectiveness of MPAs and other fishery management tools. The scope for implementation of marine reserves may be greatly increased if they can protect biodiversity and habitat while simultaneously maintaining or enhancing fishery production (Holland and Brazee, 1996).

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. 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 a MPA and the total area that should be protected have been widely discussed by biologists and economists. From the ecological perspective, Roberts (1997) suggests that MPAs with a size of 50% or more can provide particular benefits for heavily exploited fisheries. Lauck *et al.* (1998) find 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) use a deterministic framework and show 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 determine the optimal reserve size by maximising the present value of the harvest instead of maximising the sustainable yields, and conclude 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 perfect 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 & 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. 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 & 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 (2006). 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, MPAs are to be successful as an additional measure for fisheries management if all stakeholders are meaningfully involved in the planning and design phases. Thus, in order for MPAs to be effective in fishery management, further research on how fishermen and other users choose the location of their efforts and how these choices will be affected by MPAs will be needed to answer the question of whether MPAs might provide the largest benefit for the smallest cost (Sanchirico & Wilen, 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 & Wilen (2001) state that not everyone supports the expansion of marine reserves, of course, and that fishermen have been among the most vocal sceptics. 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 who advocate MPAs, the benefits that MPAs provide to 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).

Again, the differences in beliefs of stakeholders have shown that MPAs can only be effectively established and sustained if they have broad support from all stakeholders, especially from fishing communities and other local users of marine resources. Considering both social and economic aspects when designing MPAs is a necessary requirement for the success of MPAs.

3. Marine protected areas - How they can benefit for fisheries management

3.1 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 been progressed over the past century in an attempt to solve the problem of open access 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 conventional management approaches, however, seem to fail to manage fisheries sustainably (National Research Council, 2001). MPAs as an ecosystem-based approach have been advocated as an alternative aiming to restore and sustain 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 imply that marine reserves or protected areas may become vulnerable in fisheries management. 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.

The papers in this thesis are investigated in the context of an open access regime outside the MPA. We apply the open access regime to investigate whether the protected areas could contribute to fisheries management and what conditions and tools should be applied. Departing from this point, in papers 1 and 2 the protected area is created and the fisherman are allowed to freely fish outside the protected area. In paper 3 only the recreational anglers are allowed to fish inside the protected area, while the commercial fishermen only fish in outside areas as a way of examining the role of the protected area in resolving the conflicts between the different sectors.

The empirical analysis of trawlers operating around the Nha Trang Bay MPA in paper 1 again demonstrates that open access outside the MPA can lead to too much fishing. The abundance of the fish stock inside the MPA does not increase and even tends to decline in some areas after three years of establishment. This result implies that overfishing has been presented 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 run. 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 strain on fish stock capacity, thus diminishing the numbers.

The question of how MPAs can help to solve the problem of open access is also dealt with in paper 2. This paper shows that there is a possibility for the manager to adjust the fishermen’s behaviour from open access to optimal management if the manager sets up appropriate compensation payments for the economic losses of the fishermen due to the creation of marine reserves. The compensation payment is not widely applied in fisheries; however, the finding from this paper shows that it is possibly one of the key points that should be considered when establishing marine reserves as an additional measure of support for the success of the reserves.

Even though the implication from this thesis is that, 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.

3.2 Incentive-based approach and marine protected areas

Protected areas are particularly helpful in the face uncertainties (Lauck *et al.*, 1998) and can also promote resilience to shocks and raise profitability even when harvesting is optimal (Grafton *et al.*, 2005). Despite these benefits, reserves cannot address all the 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. MPAs 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 they move). The effect of MPAs on the fishermen's 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 may play an important role in achieving the expected outcomes of managers and society, depending on the size of the incentives that they are able to create. As with fisheries management, incentive payments may change the incentives for different stakeholder groups, so changing their behaviour and providing fishermen 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.

The incentive-based approach is demonstrated in paper 2, where the manager provides a payment for fishermen in exchange for operating within a conservation framework. Paper 1 does not directly investigate the incentive approach but the findings from this paper suggest considerations for incentive measures or alternative income possibilities for fishermen that can help protect fish stock. By setting appropriate payments, paper 2 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 received income.

3.3 Allocation of fishery resources and marine protected areas

The potential conflicts and interactions between different marine sectors are increasing over time; conflicts between fisheries and aquaculture and tourism, and between recreational and commercial fisheries, are particularly increasing. The most common conflict in these cases is the conflict over physical occupation of the ocean for the parties' activities. 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 area is 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. 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 measures 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 a type of spatial planning management which show their useful role in the process of resource allocation between competing sectors. Protected areas not only define the operation area for each sector, but they also may 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 a consideration of fishermen's behaviour, particularly in terms of spatial harvest allocation, and the impact that one sector may be having on another. As a result, 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. All of these issues are addressed in paper 3.

4. Summary of the papers

Paper 1

Are marine protected areas (MPAs) positive for adjacent fisheries? In this paper, we study the technical efficiency of small-scale trawlers in Nha Trang, Vietnam following the establishment of Nha Trang Bay marine protected area, which imposed a trawl ban to protect marine biodiversity and regenerate fish stocks. Data were collected through a survey of small-scale trawler owners. Using a stochastic frontier analysis, this study demonstrates that engine power, household size and operating characteristics of vessels strongly affect technical efficiency. The number of days at sea is the most important factor affecting the output revenue. Understanding these relationships is an essential condition for effective management. Despite the ban on trawling, the vessels operating in the vicinity of the MPA are still more technically efficient than those operating in an unprotected area. Thus, the alternative grounds still sustained the activity of the trawl fleet affected by the ban. However, secondary data from the NTB-MPA project indicate a reduction in fish stocks in this area. Our findings, combined with the secondary data, may provide some policy implications. An MPA and a trawl ban do not seem to be sufficient to achieve improved management. In addition, it is essential to deal with the link between poverty and resource management. Alternative income generation and effective education in order to achieve compliance from local communities are among the measures that are important for the success of an MPA.

Paper 2

Despite the fact that marine reserves provide a number of benefits, they do not provide incentives for fishermen to protect biodiversity and do not provide compensation for financial loss due to the designation of the reserves. To obtain fishermen’s support for marine reserves, some politicians have suggested that subsidising or compensating those fishermen affected by new reserves should be considered by fisheries managers. The objective of this paper is to apply the principal-agent theory, which is still rarely applied in fisheries, to define the optimal reserve area, fishing effort and transfer payment in the context of symmetric and asymmetric information between managers and fishermen. The expected optimal reserve size under asymmetric information is smaller than under symmetric information. The fishing effort with a transfer payment is always less compared to that without payment. This reflects the fact that, as the manager induces the fishermen to participate in the conservation program; the fishermen will take into account their effects on fish stock by decreasing their effort. Examples are also supplied to demonstrate these concepts.

Paper 3

This paper investigates the interactions between recreational and commercial fisheries. It introduces the idea of a protected area for recreational fisheries, as a way to reduce conflict between the two sectors and to preserve the natural resources. It is demonstrated that, without a protected area for recreational fisheries, open access may imply that only one sector survives. A protected area can ensure the operation of both sectors, even under open access. This measure also enhances the aggregate fish stock and the aggregate harvest, both in open access and in the optimal management of recreational fisheries, even if commercial fisheries operate under an open access regime.

5. Contributions of the thesis

Three essays in this thesis offer an insight into the use of MPAs for purposes of fisheries management, using different approaches. The contribution of this thesis thus should be noted. With the analyses in different contexts, the implication from this thesis is that MPAs may become valuable tools for the preservation of biodiversity and sustainable management of fisheries, especially open access fisheries, if we apply them under the right conditions.

Paper 1 is an investigation of the efficiency of fishing vessels affected by the creation of an MPA and the ban on trawlers, looking at the case of Nha Trang Bay MPA in Vietnam and the small-scale trawlers. There is some research on trawl bans following the creation of an MPA as a management tool in the Gulf of Castellammare, NW Sicily (Pipitone *et al.*, 2000; Whitmarsh *et al.*, 2003). These studies seek to investigate the change in fish biomass and economic sustainability after the trawl ban. Our paper tries to trace the state of fish abundance and biodiversity before and after the creation of the MPA and to compare the efficiency of trawlers fishing in the vicinity of the MPA with that of trawlers fishing in further-away areas. The main contribution of this paper is that it provides a solid application of stochastic frontier analysis with relatively interesting policy implications. The most important implication from this case is that, to achieve success from the creation of MPAs, fishermen must understand the need for the MPAs and support them. The stochastic frontier analysis also provides further insight into key factors which lead to increased efficiency, which becomes a useful guide for managers in managing fishing vessels.

Paper 2 examines, from a theoretical approach, the use of compensation payments as a tool for getting the support of fishermen for biodiversity conservation. The innovative contribution of this paper is that it applies the principal agent for studying marine reserves and introduces an objective function, which defines social welfare as a combination of that obtained from implementing a marine reserve and the activities from fishing. The paper appears to be the first research modelling incentive payments for biodiversity conservation in fisheries. It offers fishery managers information on how the payment can help to adjust the effort of fishermen from an open access to an optimal management objective, and how the manager can set up the payment to the fishermen and determine the reserve size in different situations regarding fishermen's private costs.

A dynamic model of recreational and commercial fisheries has been developed in paper 3 to evaluate the ecological- and fisheries-related effects of an MPA. This paper is the first attempt to model the protected area in such a way as to provide measures for resolving the conflicts and management of recreational and commercial fisheries. This paper is different from previous research (Connell & Sutinen, 1979; Bishop & Samples, 1980) in which both recreational and commercial fisheries are studied under open access or under an optimal management regime. An innovative analysis of management regimes has been presented in this paper. The recreational fishery operates under two management regimes – open access and optimal management – while the commercial fishery only operates under open access. The paper applies a bioeconomic model, which combines ecological systems and economic conditions, to analyse the consequences of alternative management regimes on the harvest and activity of each sector. The findings from this paper indicate that even if different management regimes are applied for recreational fisheries, one of the two sectors may not survive if the commercial fishery still operates under open access. The use of protected areas for recreational fisheries has shown that the conflicts between the two sectors may be resolved and their activities may be ensured. The paper thus serves as a relevant contribution to current management challenges in fisheries when facing interactions between different sectors.

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