

Untangling the Benefits of Protected Areas in Fisheries

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Abstract *Studies of marine protected areas as a tool for fisheries management have shown that protected areas have the potential to improve the level of resource rent generated in the fishery. The benefits to the fishery from protected areas have been shown to increase with sub-optimal management. However, some benefit that is derived from protected area creation in these circumstances is attributed to changes in effort levels. Both unique benefits, such as the hedge benefits of protected area creation, and non-unique benefits, such as shifts in effort levels towards optimal levels, are explored. Examples are taken from analysis of protected area creation in a predator-prey meta-population fishery under several different scenarios. It is suggested that much of the gain from protected area creation under sub-optimal management can be attributed to non-unique benefits, with the policy implications of this analysis also explored.*

Key words Bioeconomics, fisheries management, marine protected areas.

JEL Classification Code Q22.

Introduction

Protected areas have been suggested as a means to manage uncertain events in fisheries (Grafton and Kompas 2005). Uncertain shocks to biomass have caused some fisheries to collapse despite the presence of controls to ration resource use. In Grafton, Kompas, and Ha (2005), the authors provide examples of fisheries that have collapsed due to uncertain environmental events, such as the Peruvian *anchoveta* fishery, which collapsed after an *El Nino* event and the Canadian Northern cod fishery suffering a similar fate, post a negative shock in the 1980s. The authors suggest that a protected area could have been used to prevent such collapses, as they would have maintained fishery populations to a level that could have withstood the shock events.

However, protected areas can be viewed as a ‘blunt’ policy instrument for fisheries management, in the sense that they do not alter the market incentives of individual operators (Greenville and MacAulay 2006). The economic outcome from protected area use will be sensitive to, and determined by, other controls. Without

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controls that generate resource rent (the economic return to society from the resource), it is not possible for the protected area to improve the return from extracting fisheries resources. Protected areas represent an investment in natural capital, with the payoff from the investment sensitive to the mechanisms that control the use of the resource.

Despite this, models of marine protected areas in fisheries have shown that protected areas can increase resource rent. The effectiveness of protected areas as a management tool is enhanced given sub-optimal management. However, the drivers of these benefits have not been specifically analysed. Emphasis has often been placed on the unique benefits that accrue from protected area creation, such as hedge values (*i.e.*, improved harvest and resource rent from a reduction in the variability of the resource base) and improvements in resilience (*i.e.*, a return to better harvest faster after a shock event).

In this paper, the drivers of the benefits to flow from protected area creation are analysed. Past studies have found that protected areas can improve fishery outcomes under a range of conditions and management structures. The drivers of these benefits, however, are less clear. Protected areas influence effort, biomass, species biomass ratios, and the resilience of the fishery. These effects will lead to changes in resource rent. This study finds that protected areas lead to both unique (only those which can be obtained through the use of a protected area) and non-unique (those which can be obtained from a range of alternate fishery management arrangements) benefits. The focus of the study is on the changes in effort, biomass, species biomass ratios, and the unique benefits to flow from protected areas. It is found, in particular for fisheries not optimally managed, that non-unique benefits are the main drivers of the gains to accrue from protected area use as a tool for fisheries management.

Results obtained from three studies of protected area creation in a predator-prey fishery are used as the basis for the analysis. Greenville and MacAulay (2006) present a stochastic bioeconomic model of a two-species fishery in which they analyse protected area performance given the risk of stock collapse. This analysis is expanded in Greenville (2005) to examine the effects of negative shocks to the biomass, and further by Greenville and MacAulay (2007) where the model was applied to two fisheries operating in the Manning Bioregion of NSW.

The remainder of the paper is organised as follows. In the next section, the use of protected areas in fisheries management is presented. Past modelling results derived from the model set out by Greenville and MacAulay (2006) are presented, with an analysis of the benefits created through protected area creation also presented. A discussion of policy implications and concluding comments are presented in the final sections.

Marine Protected Areas and Fisheries Management

Through the preservation of entire ecosystems (both environment processes and biomass), protected areas are believed to provide a hedge against uncertain events. Stocks within protected areas potentially provide a buffer source for the surrounding fishery (Lauck *et al.* 1998). Despite this, in a two-species meta-population context, protected areas have the potential to increase the variation in harvests and resource rent depending on the current management arrangements in place in the fishery (Greenville and MacAulay 2006, 2007; Greenville 2005). For example, for a predator-prey fishery, protected area creation under open access increased harvest variation in the open fishing grounds (Greenville and MacAulay 2006).

Protected areas used in single-species open-access fisheries can lead to a gain for both fishers and society. Protected areas have been shown to increase yields

when stock levels are low (Pezzey, Roberts, and Urdal 2000; Sanchirico and Wilen 2001; Greenville and MacAulay 2004), and reduce harvest variation for a single biomass (Conrad 1999; Pezzey, Roberts, and Urdal 2000; Hannesson 2002). If increases in biomass are seen as a gain to conservationists and increases in harvests are viewed as a gain for fishers, then a ‘win-win’ outcome can be defined (Sanchirico and Wilen 2000, 2001).

Sanchirico and Wilen (2001) showed that if pre-reserve harvest equilibrium existed under certain conditions relating to cost of effort and biomass migration, the establishment of a marine protected area would yield a win-win outcome. However, Hannesson (2002) suggested that in these circumstances, the ability of protected areas to achieve their conservation objective is questionable due to the concentration of effort in the remaining area. Also, Sanchirico and Wilen (2000) argue that for limited-entry fisheries the benefits to fishers are limited, as managers are required to reduce effort post establishment.

Conrad (1999) observed two possible benefits from the creation of a marine protected area. It reduced the variation in biomass (therefore harvest), and may reduce the costs of management mistakes. Hedge benefits occurred for large protected areas (around 60% of the fishery). Similar results were obtained by Hannesson (2002), where the average catch increased and the variation of catch decreased. Hannesson (2002) suggested that the reduced variation in catch was due to the migration effect. The probability and instances where the biomass falls to the extent that it is not profitable to fish are reduced.

The effect of protected areas on harvests and resource rent was further explored by Grafton, Ha, and Kompas (2004); Grafton, Kompas, and Ha (2005); Greenville (2005); and Greenville and MacAulay (2006, 2007). Grafton, Ha, and Kompas (2004) examined the establishment of a protected area in a fishery with environmental stochasticity (normal variation in fish stocks caused by environmental conditions) and an uncertain negative shock to the biomass. Protected area establishment was found to reduce the effects of the negative shocks, effectively smoothing harvest and improving resource rent. Improvements in resource rent occurred for small-sized protected areas (around 20% of the fishery). However, Grafton, Kompas, and Ha (2005) state that the use of protected areas will not guarantee against a population collapse, but will create economic benefits through the buffer effect of higher stocks.

Methods

Greenville and MacAulay (2006, 2007) and Greenville (2005) use a predator-prey meta-population model to analyse the effects of marine protected area creation under a number of differing environmental and economic conditions. In this paper, attention is given to the drivers of the results that are reported in those papers.

The model developed by Greenville and MacAulay (2006) is used to describe a fishery with two species and two sub-populations (denoted by the subscripts). In the model, the prey (X_i) and predator species (Y_i) migrate between the sub-populations, which are assumed to occur in different patches. The equations of motion for the biological system are given by equations (1) and (2):

$$\dot{X}_i = F(X_i) - aX_iY_i + z_i^x \quad (1)$$

$$\dot{Y}_i = F(Y_i, X_i) + z_i^y, \quad (2)$$

where $F(X_i)$ and $F(Y_i, X_i)$ are the growth functions for prey and predator species in

patch i , respectively; aX_iY_i is the level of predation of prey by predators in patch i , and z_i^x and z_i^y are the dispersal relations (the superscript denotes the species to which the dispersal relationship applies).

Harvest in the fishery is assumed to follow a Schaefer (1957) production function with constant per unit cost of effort (c^j) for species j (where j equals X, Y). The Schaefer production function is represented by $h_i^j = q^j E_i^j J_i$, where h_i^j is the level of harvest of species j in patch i , q^j the catchability coefficient of species j , E_i^j the level of effort applied to species j in patch i , and J_i the level of biomass of species j in patch i .

Optimal biomass and effort in each patch is found by maximising the resource rent generated in the fishery in continuous time subject to the equations of motions (1) and (2) (full derivation in Greenville and MacAulay 2006). Optimal biomass of species j in patch i is given by equation (3) below:

$$\delta = \frac{c^j w_i^j [F_i^j(\bullet) + z_i^j]}{w_i^j [p^j q^j w_i^j - c^j]} + [F_i^{j'}(\bullet) + z_i^{j'}], \quad (3)$$

where w_i^j is the biomass of species j in patch i ($w_i^j = J_i + z_i^j$), p_i the price of species j , $F_i^j(\bullet)$ is the growth function of species j in patch i , δ the social discount rate, $w_i^{j'}$, $z_i^{j'}$ and $F_i^{j'}(\bullet)$ the first derivatives of w_i^j , z_i^j and $F_i^j(\bullet)$ with respect to biomass J_i , respectively, with all other variables as defined with subscripts indicating patch and superscripts species. From the optimal steady-state biomass condition, equation (3), the instantaneous internal rate of return (right-hand side) should be equal to the external rate of return (discount rate) and is influenced by the level of migration $z_i^{j'}$, z_i^j (Greenville and MacAulay 2006). If z_i^j is positive (that is an inflow), the optimal level of biomass in the exploited patch is lower than the case with links between sub-populations (described by Clark 1990, p. 95). In order to achieve the maximum net present value, 'imported' biomass is substituted for biomass in the open patch (Greenville and MacAulay 2006).

Using the predator-prey interaction described by Ströbele and Wacker (1995) and set out in Greenville and MacAulay (2006a), the equations of motion are given by:

$$\dot{X}_i = X_i \left[r \left(1 - \frac{X_i}{K_i} \right) - aY_i \right] + z_i^x - q^x E_i^x X_i \quad (4)$$

$$\dot{Y}_i = Y_i \left[s \left(1 - \frac{bY_i}{X_i} \right) \right] + z_i^y - q^y E_i^y Y_i, \quad (5)$$

where r is the intrinsic growth rate of prey, s the intrinsic growth rate of predators, K_i the carrying capacity of patch i , a and b the predation parameters (assumed to be greater than zero), and all other variables as previously defined.

Dispersal between patches is assumed to take two forms; density-dependent or sink source. Density-dependent flows are those which are driven through differences in the relative densities of population in different patches, whilst sink source flows are uni-directional in which biomass flows from one patch to another (Conrad 1999). A density-dependent flow is shown in equation (6), taking the prey species as the example:

$$z_i^x \equiv g^x \left(\frac{X_j}{K_j} - \frac{X_i}{K_i} \right). \quad (6)$$

A sink-source flow is shown in equation (7) for the source patch. The sign on the flow is positive for the sink patch:

$$z_i^x \equiv -g^x \left(\frac{X_i}{K_i} \right). \quad (7)$$

In addition to the model described in Greenville and MacAulay (2006), in Greenville (2005) effort is assumed to be endogenously determined. Effort in the fishery is assumed to respond imperfectly to changes in fishery rent captured by individual fishers (through variations in harvest caused by environmental stochasticity and shocks to the biomass). The change in effort, where u is the adjustment parameter ($u < 1$ for imperfect adjustment), is given by:

$$\dot{E}_i^j = E_i^j [1 + u(p^i q^i J_i - c^j)]. \quad (8)$$

Previous Results from Protected Area Creation

In Greenville and MacAulay (2006), the bioeconomic model was used to analyse protected area creation in a fishery subject to a risk of stock collapse. The creation of a protected area was assumed to offset the risk of stock collapse in the fishery due to the protection of both species and habitats. Given a 5% stock collapse risk (which was assumed to follow a Poisson distribution), protected areas of 15, 20, and 25% of the fishery maximised the resource rent generated under optimal, 75% of optimal, and 50% of optimal steady-state biomass, respectively. The opportunity costs curves, which represent lost resource rent under density-dependent dispersal, are given in figure 1. With sink-source dispersal, the opportunity costs of protected area creation were found to be greater, as there is no feedback of biomass into the protected area, making the flow out of the protected area greater and more variable (Greenville and MacAulay 2006).

Greenville (2005) removed the assumption that protected area creation would offset the risk of collapse to the fishery by examining protected area performance when the fishery was subject to negative shocks to the biomass. The chance of a negative shock was assumed to occur, with some probability, in years 15 and 40 over a 100-year horizon for a fishery in steady state. The uncertain event led to a sudden fall in fish stocks by 25%.

Several different management arrangements were modelled in Greenville (2005). Protected area creation in a fishery where the tax on effort led to optimal steady-state biomass, and which had density-dependent dispersal, did not increase mean resource rent (the authors suggested that it was likely that an increased effect of the negative shock would mean protected areas would create some increase in mean resource rent). Under a tax which led to sub-optimal steady-state biomass, the protected area improved the total mean resource rent. The limited benefit given density-dependent dispersal was due to the shock affecting both patches, limiting the initial dispersal post the shock event.

However, for sink-source dispersal Greenville (2005) found that protected areas increased mean resource rent (figure 2). The increase in mean resource rent was due to faster biomass recovery in the protected area, increasing the dispersal post the rates shock. The benefit under sink-source was created, as there was no feedback; meaning the flow of biomass was greater after the shock compared with density-dependent dispersal, improving the speed the fishery returns to steady-state and thus the resource rent.

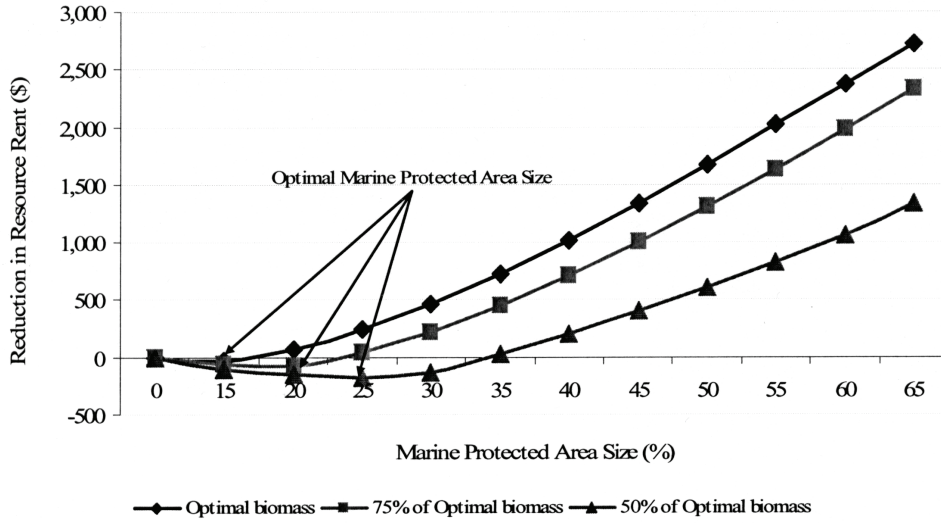


Figure 1. Opportunity Cost of Protected Area Creation under Density-dependent Dispersal and Stock Collapse

Notes: $r_1=0.8$, $s=0.6$, $g^x=g^y=2$, $q^x=0.01$, $q^y=0.01$, $p^x=20$, $p^y=30$, $c^x=1.5$, $c^y=1$, $b=2$, $a=0.02$.

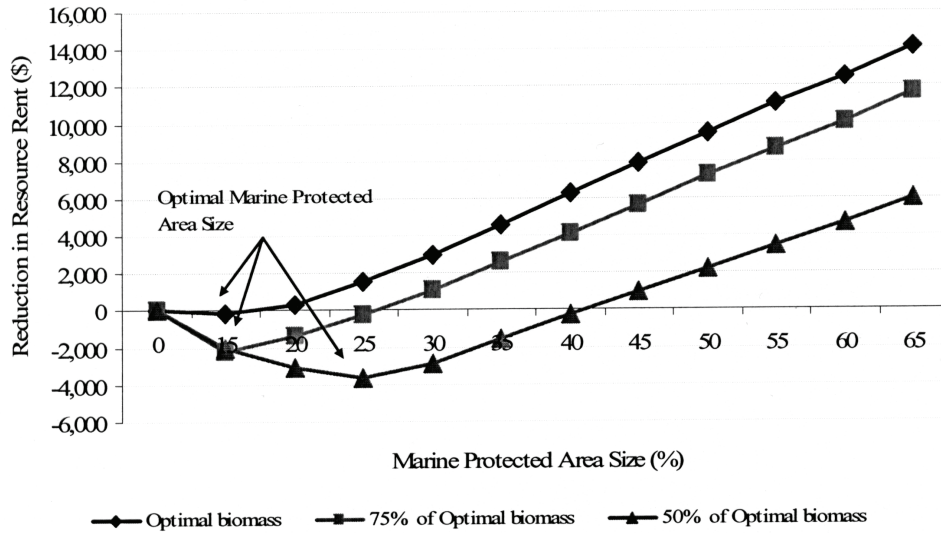


Figure 2. Opportunity Cost of Protected Area Creation under Sink-source Dispersal and Negative Shock

Notes: $r=0.8$, $s=0.6$, $g^x=g^y=2$, $q^x=0.01$, $q^y=0.01$, $p^x=20$, $p^y=30$, $c^x=1.5$, $c^y=1$, $b=2$, $a=0.02$, $u=0.02$.

In Greenville and MacAulay (2007), the model was applied to the fishing industry located in the southern part of the Manning Bioregion in NSW. Two fisheries, the ocean prawn trawl and the ocean trap and line, were isolated for the analysis, as they best represented fisheries that caught prey and predator species, respectively. For the prey species, a weather variable (rainfall) was added to the model due to the reliance of the prey species (mostly prawns) on fresh water flow into estuaries. As the dispersal level was not known, varying dispersal levels were examined.

The net cost, in terms of forgone resource rent under density-dependent dispersal, is depicted in figure 3. For all dispersal levels, there is a slight diminishing cost of protected area establishment until very large protected areas are established. From figure 3, for g equal to 3, an optimal-sized protected area exists close to 15% of the total fishery. This increased to 20% when g is equal to 4.

For the sink-source dispersal case, benefits were lower and a minimum-sized protected area was required to obtain a net benefit. Lesser benefits accrued, compared with density-dependent dispersal, because of the difference in the dispersal drivers. The difference between the population densities post protected area creation was large, especially for predators, resulting in extra flow from the protected area under density-dependent dispersal.

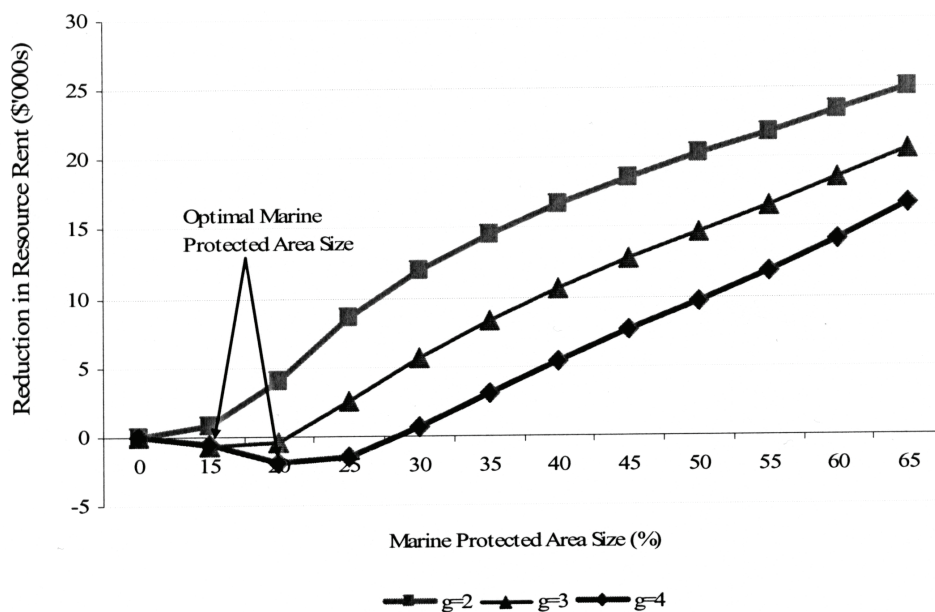


Figure 3. Opportunity Cost of Protected Area Creation (Non-optimal Management) under Density-dependent Dispersal-Manning Bioregion

Notes: $r=0.416$, $s=0.518$, $q^x=0.1$, $q^y=0.1$, $p^x=8$, $p^y=4.75$, $c^x=4.9$, $c^y=1.1$, $b=0.1$, $a=0.005$.

Analysing the Benefits of Marine Protected Areas in Fisheries Management

The benefit from protected area establishment in a fishery is derived from four sources. First, in non-optimally managed fisheries, protected areas potentially reduce the level of effort expended in the fishery. Second, unique aspects of protected areas exist, such as the ability to hedge against uncertainty (improving resilience) and environmental stochasticity. Third, protected areas can cause a shift in biomass towards the optimal level. Fourth, the establishment of a marine protected area in multi-species fisheries influences the resource base (changing population proportions). These benefits are discussed in this section.

Benefits through Effort Reductions

With the creation of a protected area, lost access may result from a fall in effort. Given taxes on effort which lead to sub-optimal biomass, the fall in effort will shift aggregate effort closer to optimal levels. This shift will reduce the level of total cost in the fishery and improve the resource rent.

The shift in effort closer to optimal levels is, however, not a unique benefit of a protected area. The reduction in effort could be achieved through other policies. If this gain is included in the benefit to accrue from a protected area, it will overstate the unique fishery benefits from protected area creation. Only if other mechanisms cannot be used to reduce the level of fishing effort in a fishery should this benefit be classified as a unique benefit from protected area creation. The difference between actual and optimal mean steady-state prey effort in a fishery with stock collapse and density-dependent dispersal are given in figure 4.

The optimal mean effort levels chosen for comparison are those determined using equation (3), and are sub-optimal for certain-sized parks given the risk of stock collapse. It is for this reason that under a tax that led to optimal steady-state biomass, effort is below the optimal level. For a tax on effort that led to 75% optimal steady-state biomass, a protected area of 15% of the fishery reduced prey effort to optimal levels. For predator effort in a fishery with uncertain shocks to the biomass, much smaller protected areas are required to achieve optimal aggregate effort levels in the fishery than for prey.

When the fishery was subject to stock collapse and dispersal followed the sink-source relationship, effort shifted away from optimal levels under all forms of management. The difference between actual mean predator effort in a fishery with stock collapse and sink-source dispersal is given in figure 5. For a tax that led to optimal steady-state biomass levels, the creation of a small-sized protected area increased mean predator effort. Under sink-source dispersal, effort applied to predators was much closer to optimal levels for all sizes of protected areas and management controls. This occurred due to a relatively large increase in predator numbers in the protected area, and thus dispersal. For sink-source dispersal, the lack of feedback led to a greater flow of biomass from the protected area.

Based on the parameter estimates for the Manning Bioregion, a large difference between both the level of biomass and species biomass ratios within the fishing ground and the protected area existed (Greenville and MacAulay 2007). For the prey species, the protected area caused mean effort levels to shift towards optimal aggregate levels. The creation of a marine protected area under sub-optimal management (based on current management arrangements) and sink-source dispersal led to a fall in effort towards optimal levels. However, it is not until the protected area is very large that actual mean levels of effort reach aggregate optimal levels. Given a tax on

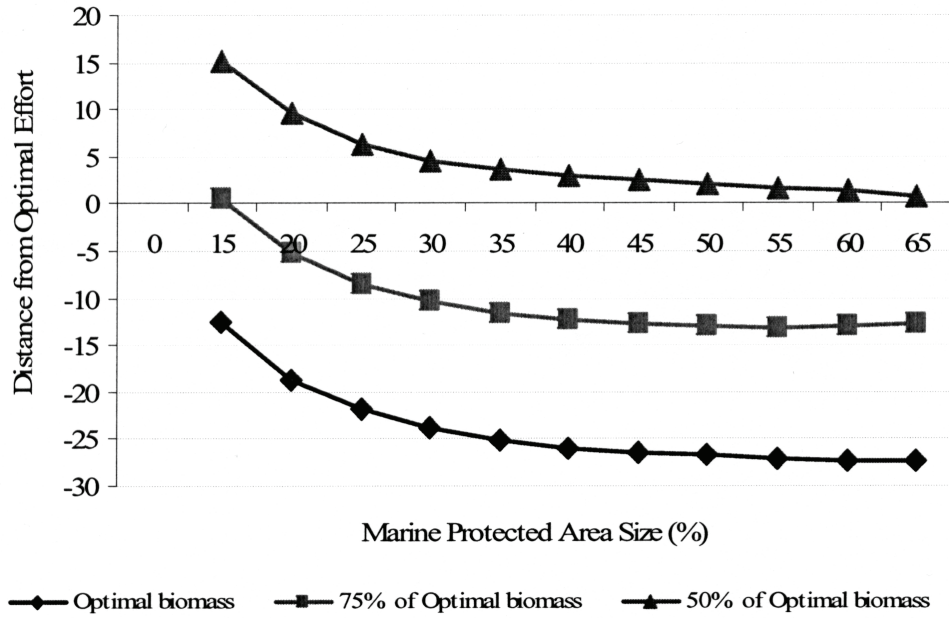


Figure 4. Distance from Optimal Prey Effort under Density-dependent Dispersal and Stock Collapse

Notes: $r=0.8$, $s=0.6$, $g^x=g^y=2$, $q^x=0.01$, $q^y=0.01$, $p^x=20$, $p^y=30$, $c^x=1.5$, $c^y=1$, $b=2$, $a=0.02$.

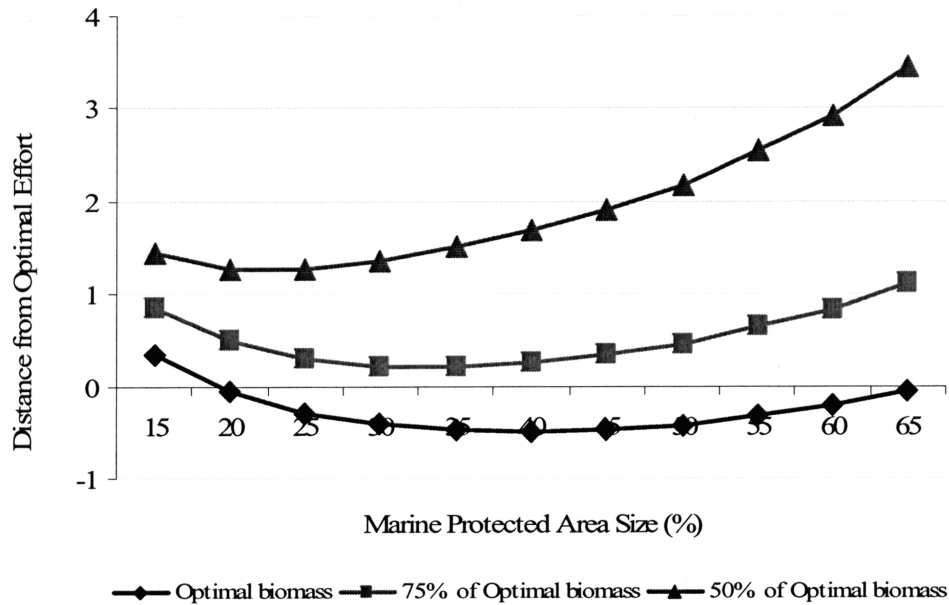


Figure 5. Distance from Optimal Predator Effort under Sink-source Dispersal and Stock Collapse

Notes: $r=0.8$, $s=0.6$, $g^x=g^y=2$, $q^x=0.01$, $q^y=0.01$, $p^x=20$, $p^y=30$, $c^x=1.5$, $c^y=1$, $b=2$, $a=0.02$.

effort which led to optimal steady-state biomass levels, the protected area caused a fall in total effort for all protected areas sizes.

As there was a large difference between the ratio of species biomass in the protected area and the surrounding fishing ground, there was a significant flow of predator biomass from the protected area, increasing effort in the surrounding fishing ground for controls, which led to sub-optimal steady-state biomass. This result is different from the other scenarios. The shift in effort represents an increase in fishing pressure in the surrounding fishery, despite the maintenance of the current level of control. Further, from this result the ability of protected areas to improve non-unique benefits in terms of effort are diminished given large differences in the species ratio between the protected area and fishing ground.

It has been shown that small-sized protected areas have the potential to shift aggregate effort towards optimal levels, with the exception of when the exploited species biomass ratio is significantly different to the unexploited species biomass ratio. As aggregate effort was chosen as the point of comparison, when effort reaches optimal levels, effort in the open fishing ground is greater than own patch optimal levels and is unlikely to maximise resource rent. Despite this, the change in effort levels caused through protected area creation is significant, and plays a significant role in determining the optimal protected area size given sub-optimal management.

Unique Benefits of Marine Protected Areas

The unique benefits of protected area creation can be examined through changes in mean steady-state resource rent under optimal steady-state biomass. Protected areas influence rent through hedge effects and changes in how the fishery responds post a negative shock. Two unique benefits of protected area creation are identified. First, protected areas influence the resilience of the fishery, and second, protected areas influence the variation of rent and aggregate harvests.

With stock uncertainty, protected areas have the potential to improve the resilience of the fishery through the preservation of both species and habitats. The stocks within the protected area act as a buffer source, allowing the fishery to recover to steady state faster than without a protected area (Pimm 1984 and Grafton, Ha, and Kompas 2004). Changes in the steady-state levels of resource rent for both the negative shock and stock collapse scenarios are shown in figure 6 for sink-source dispersal (similar results for negative shock scenarios). The results under sink-source dispersal were more significant (in value terms) than those under density-dependent dispersal, with certain sizes of protected areas improving the mean resource rent under both scenarios. For density-dependent dispersal, a protected area of 15% of the fishery was optimal, given stock collapse. For sink-source dispersal, a protected area of 15% of the fishery was optimal for both the stock collapse and negative shock scenarios.

The greater benefit under sink-source dispersal was due to the enhanced resilience effect. With sink-source dispersal, movements of biomass from the protected area to the adjoining fishing ground are independent of relative stock densities. This increased dispersal has a greater smoothing effect on harvest, effort, and resource rent. Periods of low growth in the fishing ground are supplemented through the flow from the protected area. This flow would not be as great with density-dependent dispersal in instances when the protected area also had low growth.

In the presence of a negative shock to the biomass, the ability of a protected area to improve the 'pimm-resilience' is enhanced (Grafton, Kompas, and Ha 2005). If the shock affects the protected area and fishing ground equally, then post the event the change in the relative densities is the same. Thus, under density-dependent

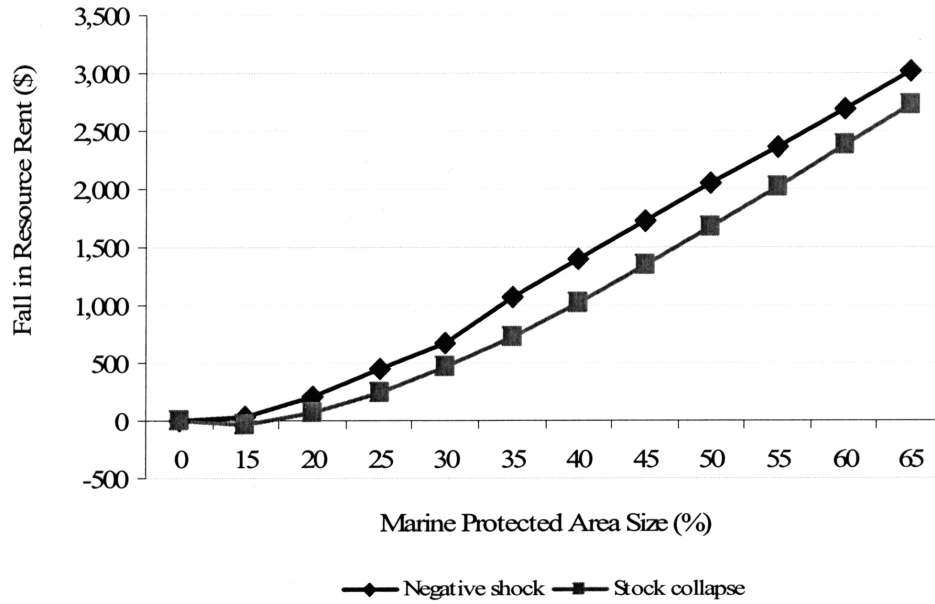


Figure 6. Opportunity of Marine Protected Area Creation with Optimal Biomass and Density-dependent Dispersal

Notes: $r=0.8$, $s=0.6$, $g^s=g^y=2$, $q^s=0.01$, $q^y=0.01$, $p^s=20$, $p^y=30$, $c^s=1.5$, $c^y=1$, $b=2$, $a=0.02$, $u=0.02$.

dispersal, the flow would remain relatively stable. With sink-source dispersal, as the biomass in the protected area is greater, the flow post the negative shock is relatively greater. This results in the fishery returning to a steady state faster than otherwise, improving resource rent.

When the fishery was not subject to uncertainty, the effect of dispersal on the protected area outcomes differed. Based on estimates from the Manning Bioregion fisheries, density-dependent dispersal led to the greatest benefit. This was due to large differences in population densities between the protected area and open fishing grounds. As predators were fished relatively intensely, the creation of a protected area increased predator numbers significantly. With dispersal based on differences in relative patch densities, a significant flow of biomass from the protected area was created.

The second unique benefit to accrue from protected area creation is on the variation of harvests and resource rent. In the two-patch, meta-population model used for the analysis, the protected area increased the variation of harvests for both species in the remaining fishing grounds. Despite this, protected areas generally decreased the variation of aggregate biomass, harvests, and resource rent.

The fall in the variation of resource rent and other variables is due to the smoothing of harvests through the dispersal from the protected area. The difference between resource rent per standard deviation with and without a protected area is given in figure 7 for density-dependent dispersal and stock collapse. The greatest reduction in resource rent per standard deviation occurs when 30% of the fishery is protected. The size that maximises the resource rent in the fishery will be less than that required to gain the greatest hedge benefit.

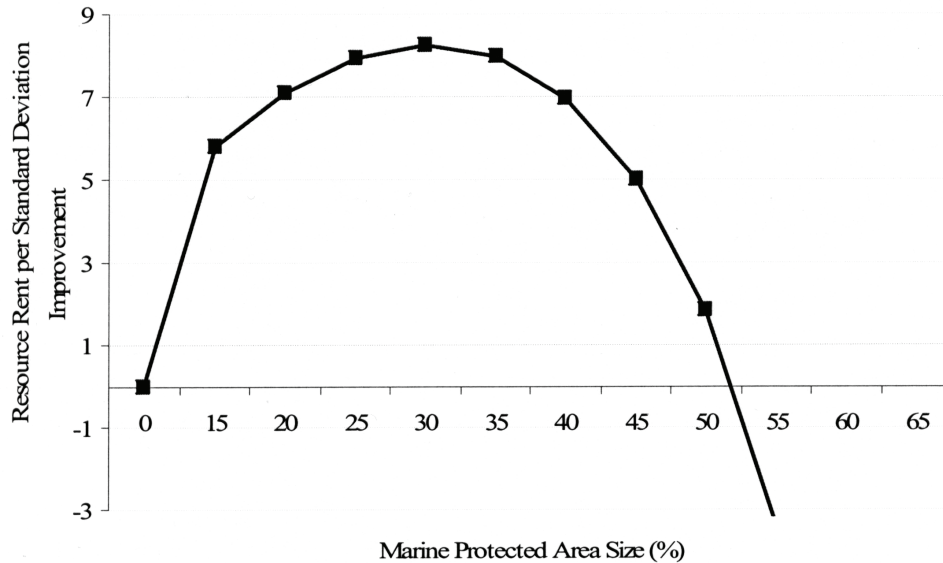


Figure 7. Total Resource Rent per Standard Deviation Improvement under Density-dependent Dispersal and Stock Collapse

Notes: $r=0.8$, $s=0.6$, $g^x=g^y=2$, $q^x=0.01$, $q^y=0.01$, $p^x=20$, $p^y=30$, $c^x=1.5$, $c^y=1$, $b=2$, $a=0.02$.

The results of changes in resource rent per standard deviation given a negative shock are significantly different than those obtained under stock collapse due to the nature of the analysis. Under this scenario, both the protected area and fishing ground were subject to the same shock event. For protected areas comprising less than 60% of the total fishery, there was a minimal change in the level of resource rent per standard deviation. Although returning the biomass in the fishing ground to a steady-state faster, the flow of biomass was not large enough to reduce the variation of resource rent for smaller-sized protected areas. The smoothing effect was only seen for very large protected areas, as the flow of biomass from the protected area was significant.

The results of changes in the level of resource rent per standard deviation in the Manning Bioregion are shown in figure 8. For a tax placed on effort that led to sub-optimal, steady-state biomass, the protected area led to some hedge benefits. For most sized protected areas under a tax on effort that led to optimal steady-state biomass, the protected area caused a fall in the resource rent per unit of standard deviation. The major cause of this was due to the fall in resource rent, which was significant for larger-sized protected areas. Despite this, the variation in mean resource rent fell with a tax on effort, which led to optimal steady-state biomass levels as a result of protected area creation.

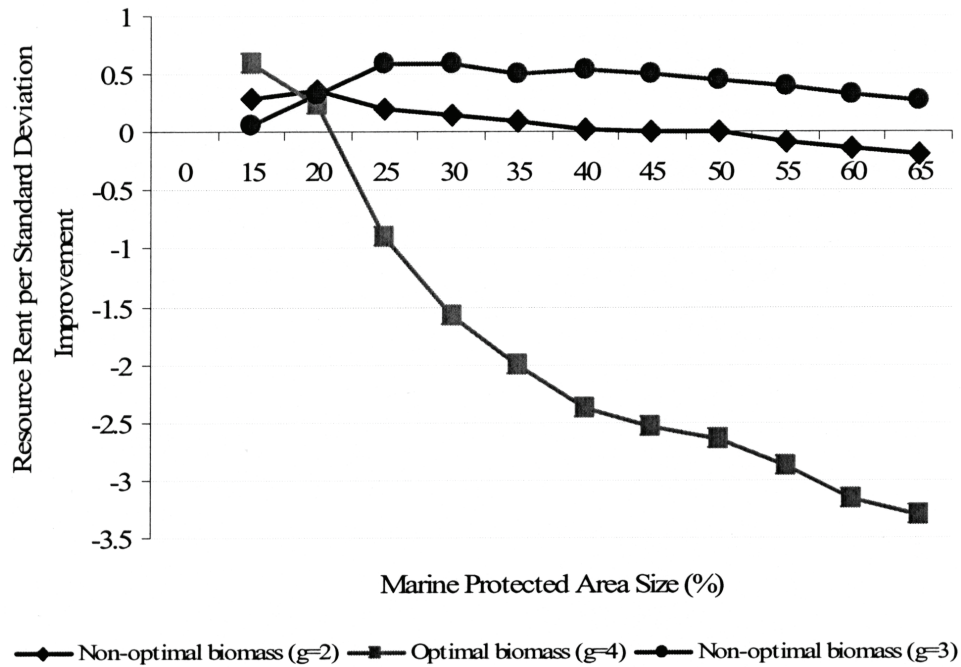


Figure 8. Total Resource Rent per Standard Deviation Improvement under Density-dependent Dispersal—Manning Bioregion

Notes: $r=0.416$, $s=0.518$, $q^1=0.1$, $q^2=0.1$, $p^1=8$, $p^2=4.75$, $c^1=4.9$, $c^2=1.1$, $b=0.1$, $a=0.005$.

Benefits through Changes in Species Biomass Levels

In a multi-species context, the creation of a protected area in a fishery is likely to change species biomass and ratios. The protected area increased the overall level of biomass in the fishery. Given non-optimal, steady-state biomass, the increase in biomass will shift aggregate biomass towards optimal levels (although exploited biomass levels in the remaining fishing grounds will remain at sub-optimal levels). As a certain amount of this extra biomass will be harvested through its dispersal to the surrounding fishing ground, it will have a positive effect on harvest, effort, and rent.

The effect from increased biomass is not a unique benefit from protected area creation, as it could be achieved through more stringent controls on fisher behaviour. If current impediments to the management of the fishery inhibit the preservation of biomass at optimal levels, then a protected area can be viewed as an adequate management tool that can be used to increase biomass within the fishery. Changes in the difference between actual and optimal mean prey biomass levels for density-dependent dispersal and stock collapse are shown in figure 9.

As with changes in effort, the creation of a protected area shifts biomass towards optimal levels with a tax on effort which leads to sub-optimal biomass. However, as optimal aggregate biomass levels are examined, these shifts will not mean that the resource rent generated from the exploitation of these stocks will be maximised, as biomass is not optimal in each patch. With a tax on effort, which led

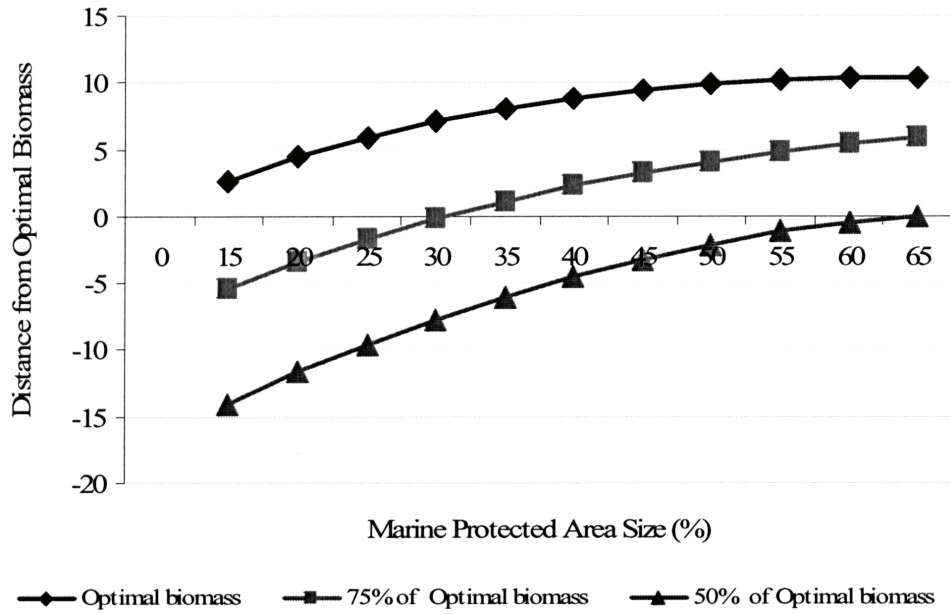


Figure 9. Distance from Optimal Prey Biomass with Density-dependent Dispersal and Stock Collapse

Notes: $r=0.8$, $s=0.6$, $g^x=g^y=2$, $q^x=0.01$, $q^y=0.01$, $p^x=20$, $p^y=30$, $c^x=1.5$, $c^y=1$, $b=2$, $a=0.02$.

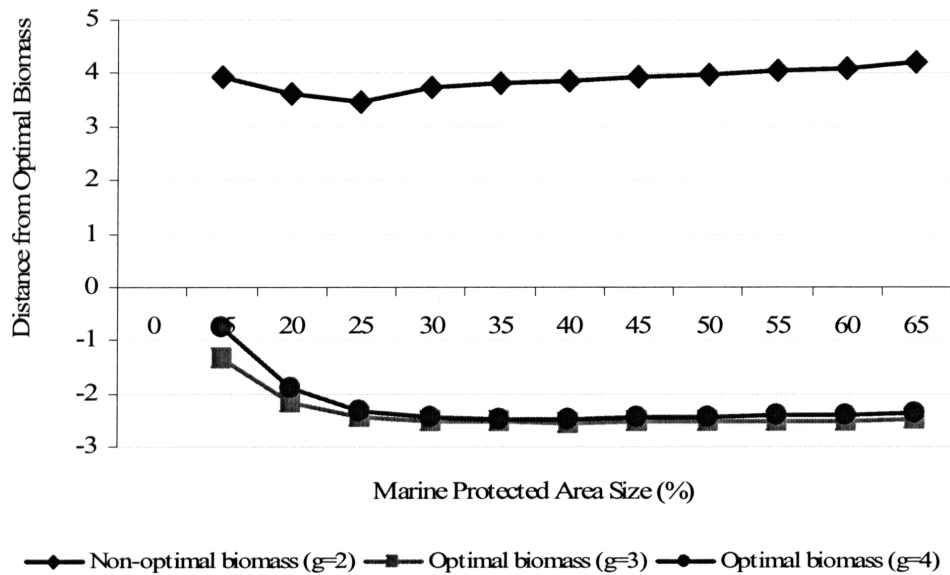


Figure 10. Distance from Optimal Predator Biomass with Density-dependent Dispersal—Manning Bioregion

Notes: $r=0.416$, $s=0.518$, $q^x=0.1$, $q^y=0.1$, $p^x=8$, $p^y=4.75$, $c^x=4.9$, $c^y=1.1$, $b=0.1$, $a=0.005$.

to 50% of optimal steady-state biomass levels, biomass in the fishery reaches optimal levels for very large protected areas. With sink-source dispersal, larger-sized protected areas were required to reach optimal biomass levels with a tax on effort which led to sub-optimal steady-state biomass due to the greater level of dispersal.

Changes in predator biomass levels under density-dependent dispersal for the Manning Bioregion are given in figure 10. Unlike the two cases of uncertainty, the creation of a marine protected area under a tax that led to sub-optimal, steady-state biomass levels caused a shift away from optimal biomass for predators. Despite the shift away from optimal levels, it was closer with a protected area than without.

Benefits through Changes in Species Biomass Ratio

The change in species biomass ratio can be used to indicate how the protected area affected different fisheries targeting different species. Changes in the species biomass ratio of prey to predator with density-dependent dispersal and stock collapse are shown in figure 11. With the fall in the species biomass ratio, a shift in overall biomass of the fishery towards predator species occurred. Under all management arrangements, the creation of a protected area caused a fall in the species biomass ratio within the fishery.

With sink-source dispersal and negative shocks to the biomass, the mean biomass of predators increased greater than that of prey for all protected areas, causing the species biomass ratio to fall. Due to the difference in the dispersal relationships, the optimal species biomass ratio of prey to predators under sink-source dispersal is greater than that under density-dependent dispersal.

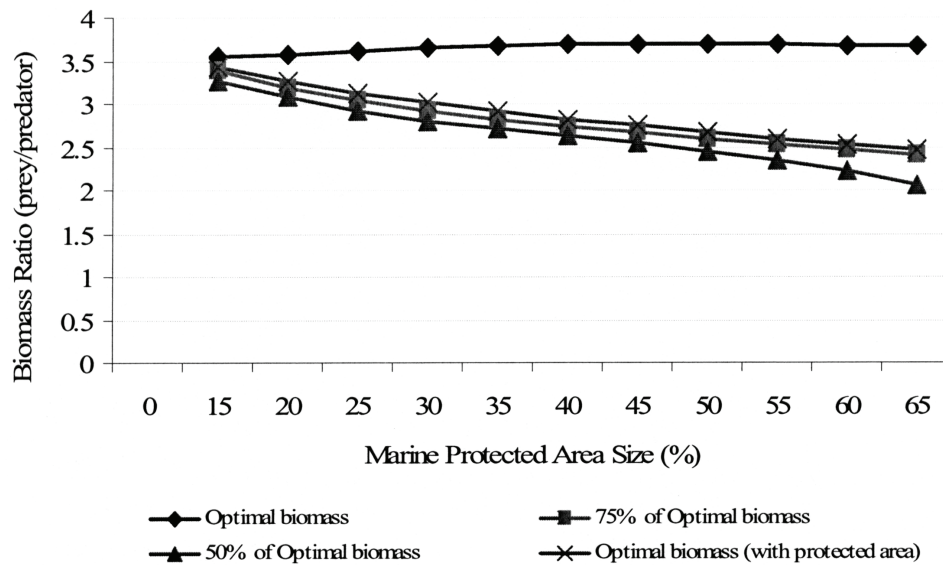


Figure 11. Change in Species Biomass Ratio with Density-dependent Dispersal and Stock Collapse

Notes: $r=0.8$, $s=0.6$, $g^x=g^y=2$, $q^x=0.01$, $q^y=0.01$, $p^x=20$, $p^y=30$, $c^x=1.5$, $c^y=1$, $b=2$, $a=0.02$.

For the Manning Bioregion, despite a movement of predator biomass away from optimal levels, the species biomass ratio shifted towards what was optimal. With the estimated current level of control, the biomass ratio was too high, meaning that predators were relatively overfished. Changes in the species biomass ratio in the Manning Bioregion with different forms of control are shown in figure 12. Under this scenario, the small-sized protected areas have the greatest effect on changing the species biomass ratio towards optimal levels.

The fall in the species biomass ratio in the fishery due to protected area creation under all scenarios is caused through a rebalancing of the populations to unexploited levels. With relatively high levels of predators (harvest), prey biomass has the potential to be greater than otherwise. When fishing is prevented, the population of predators increased significantly, with a much smaller increase seen in prey biomass, causing a change in the species biomass ratio.

The creation of a protected area will have distributional effects on the fishing industry if different fisheries target different species separately, as was the case in the Manning Bioregion (see Greenville and MacAulay 2007). Fishers targeting predator species are likely to gain from the establishment of a protected area, as the aggregate biomass of this species is greater, leading to both greater unique benefits (resilience and variation) and harvests (greater dispersal).

For fisheries that target prey species, the benefits of protected area creation are lessened. The increased predation within protected area boundaries limited the unique benefits of the protected area. Fishers who operate in these fisheries are likely to see only small benefits from protected areas unless the predation effect is very small.

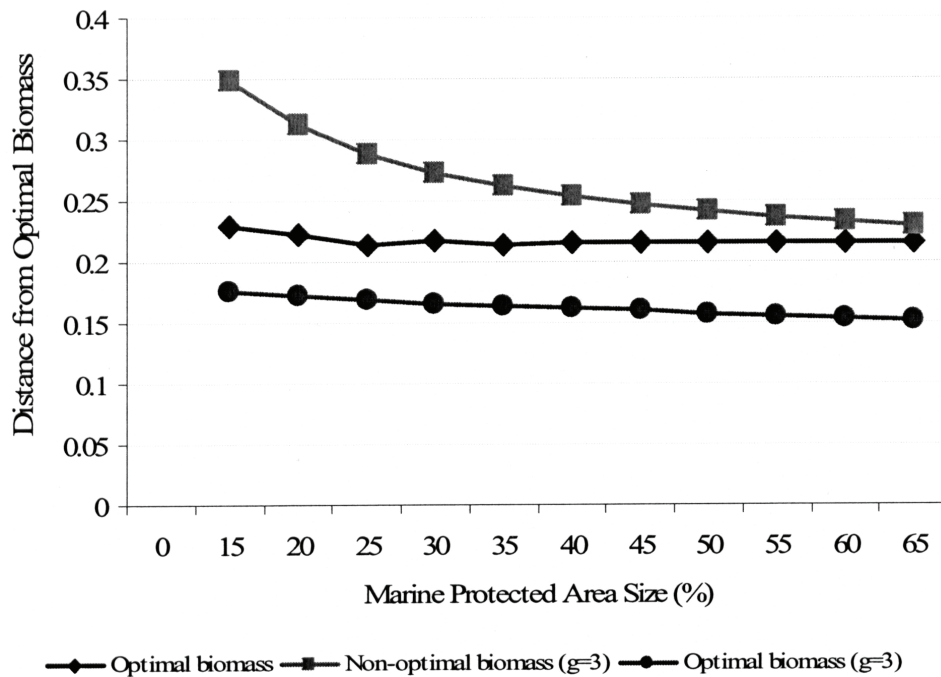


Figure 12. Change in Species Biomass Ratio with Sink-source Dispersal—Manning Bioregion

Notes: $r=0.416$, $s=0.518$, $q^x=0.1$, $q^y=0.1$, $p^x=8$, $p^y=4.75$, $c^x=4.9$, $c^y=1.1$, $b=0.1$, $a=0.005$.

Summary

A qualitative summary of the results from the studies described above is given in table 1.

Table 1
Summary of Results

Benefits	Conditions	Unique or Non-unique	Benefits
Effort reduction	Sub-optimal management	Non-unique	Small-sized protected areas (less than 30% of fishery)
Improved resilience	Sub- and optimal management	Unique	Improvement in resource rent for small-sized protected areas; greatest hedge for medium-sized protected areas (35–65% of fishery)
Biomass shift	Sub-optimal management	Non-unique	Medium- to large-sized protected areas (above 65% of fishery)
Change in resource base	Sub-optimal management	Non-unique	Small-sized protected areas

Discussion

The benefits from protected area creation in fisheries have been classified as unique and non-unique. Due to the simulation process, it was not possible to independently measure both forms of benefits in value terms. However, with controls that led to sub-optimal biomass, the non-unique benefits from protected area creation are likely to be large.

Protected areas in fisheries may be an optimal policy choice to achieve the non-unique benefits of protected area creation. Protected areas have been argued as a relatively low-cost management tool, due to lower monitoring and enforcement costs. Thus, the use of a protected area offers a solution to the problems of over extraction for lower transaction costs, which may erode the non-unique benefits under different policy instruments. If this is the case, then a protected area larger than is required to maximise the unique benefits could form part of an optimal fisheries management strategy. Whether the protected area is larger or smaller than the size that maximises both the unique and non-unique benefits of protected area creation would depend on the level of transaction costs involved in using alternative policy instruments.

Protected areas can form part of an optimal fisheries management strategy due to the unique benefits that are created. The ability of a protected area to both improve the resilience of the fishery and smooth fluctuations in environmental stochasticity have been shown to lead to increases in mean resource rent. Generally, the resilience benefits were maximised for small-sized protected areas, whereas the reduced environmental stochasticity benefits were maximised for larger protected areas.

When the fishery was subject to uncertainty, it was seen that protected areas improved mean resource rent. Along with this, the protected area also caused a fall in level of effort applied to each species. Optimal steady-state management of the fishery ignoring uncertainty, results in a level of exploitation and effort which is too great to maximise the value of the fishery.

The dispersal system between the protected area and the surrounding fishing ground plays an important role in the magnitude of the unique benefits. Given uncertainty, sink-source dispersal increased the benefits from protected area creation, as stock movements occurred independently of relative population densities. The independent flow improved the ability of the protected area to hasten the return of the fishery to a steady state. This was not the case for large differences in population densities pre- and post-protected area creation.

The difference in dispersal results will affect protected area design within fisheries. If a protected area is to be used as a tool to manage the fishery, the area chosen will be important. If the area chosen forms a source sub-population for the surrounding fishing ground, then the unique benefits of the protected area to the surrounding fishing ground are likely to be maximised. However, in the case where the protected area leads to large differences in population densities, and there is density-dependent dispersal, the unique benefits are likely to be greater than under sink-source dispersal.

Concluding Comments

Protected areas in fisheries produce a number of benefits. These benefits were classified into unique and non-unique benefits. The unique benefits were seen as improvements in the resilience of the ecosystem to environmental shocks and the hedging of environmental stochasticity. The non-unique benefits were classified as having the ability to be achieved through other policy mechanisms. The non-unique benefits discussed were changes in effort levels, biomass, and species composition.

For the unique benefits, environmental characteristics were significant in determining the outcome of protected area creation. Sink-source flows were shown to be the most beneficial to the fishery, as the stocks provided a greater buffer source. However, given large differences in exploited and unexploited biomass ratios, density-dependent dispersal is likely to enhance the unique values of protected areas.

For the non-unique benefits, protected areas were seen as an effective means to reduce effort and improve biomass to optimal levels. Further, given large differences in the species biomass ratio pre- and post-protected area creation, the establishment of a protected area shifted the species biomass ratio in the fishery towards optimal levels. Whether protected areas should be used to achieve these outcomes is determined by the relative transaction costs of differing policy instruments. The low-cost nature of protected area management may mean that this policy instrument is the best choice to achieve these outcomes.

The analysis presented here examined the benefits of protected areas to fisheries. The focus of the study was placed on the benefits to flow to a fishery if a protected area was used solely as a tool for fisheries management. Marine protected areas also have the potential to generate a range of other benefits, such as recreational values, non-use values, and potential improvements in consumer surplus from fish caught within fisheries that use these areas as a management tool. These other benefits would need to be considered when determining whether or not a protected area should be created.

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