Economics of Marine Protected Areas as a Tool for Fisheries Management

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EXTENDED ABSTRACT

The use of marine protected areas as a fishery management tool has been suggested as a hedge against management failures and variation in harvests. If successful, protected areas have the potential to increase the level of resource rent derived from the extraction of fishery resources.

In this paper, a stochastic bioeconomic model of a multi-species fishery is used to test the performance of protected areas as a management tool in a two patch, two species fishery with heterogeneous environments. The differences in the environments occur through each patch having its own growth rates and internal dynamics. Protected areas are analyzed under density-dependent and sink-source dispersal relationships between the environments within the fishery. These relationships define the drivers of the dispersal of biomass, and as such, will influence the outcome from protected area creation.

The model is applied to a section of the NSW fishing industry located in the Manning Bioregion. The NSW Government has committed to the establishment of a representative system of marine parks in coastal waters. The aim of protected area creation is to protect unique elements of NSW marine habitats. The primary focus for protected area establishment is not as a tool for fisheries management; however, it is likely to lead to some effects on the NSW commercial fishing industry. In 2004, an assessment of the Manning Self Bioregion, which spans north of the Hunter river to north of Nambucca Heads, was completed and identified an area between Stockton Beach and Wallis Lake as the likely area for a new marine park

The results from the model under the assumption homogenous catch show that protected area can be used as a fisheries management tool in the Manning Bioregion under certain conditions. Both the nature and extent of the dispersal from the protected area are key features in determining the economic outcome from protected area creation. The greater the level of dispersal, the greater the benefits from protected area establishment as more of the biomass that occurs within the protected area is likely to flow to the surrounding fishery, offsetting the effects of reduced fishing area. The value of small sized protected areas is enhanced through the density-dependent flows. Under sink-source flows, differences in relative densities do not encourage increased flows from the protected areas due to differences in patch population density, making the level of dispersal more dependent on protected area size. Given this, when sink-source flows are likely, a minimum size protected area is required before benefits to the fishery can be obtained.

The creation of a marine protected area in the Manning Bioregion is likely to have different distributional effects on the two fisheries examined in this paper. For the prey fishery, the Ocean Prawn Trawl Fishery, the benefits of protected area creation are limited by the effects of predation. As such, the protected area is less likely to increase harvests and fishery rent post establishment. Further, certain sized protected areas increased the variability of harvests, meaning that overall harvests were not only reduced but more variable. The counter occurred for the predator fishery, the Ocean Trap and Line Fishery, which is more likely to benefit from protected area creation as increased prey and the removal of fishing pressure increased the biomass of targeted species in the fishery. Despite the potential gain, in the open fishing grounds harvests of these species is likely to become more variable.

For the two fisheries as a whole, the creation certain sized protected areas can yield some hedge benefits in terms of overall harvests and resource rent. However, for this to occur, a minimum size is required. Small sized protected areas are less likely to yield hedge benefits to the fishery, with medium to large more likely. The reason for this is that smaller sized protected areas do not increase biomass greatly above exploited levels, reducing the ability for biomass in the protected area to reduce normal fluctuations in populations caused through environmental stochasticity.

1. INTRODUCTION

Marine protected areas are a spatial management control which can be used in fisheries to manage the activities of individuals. Many current non-spatial control measures have been unable to prevent concentrations in fishing effort. Input controls have lead to effort creep within fisheries through incentives to substitute controlled for uncontrolled inputs (Wilen 1979) and Fishery quotas have failed to improve the economic outcome in fisheries through potential ‘race-to-fish’ incentives.The use of marine protected areas has been advocated to overcome some of the problems that arise from non-spatial controls. Protected areas allow fishery managers to manage the activities of operators on a spatial scale through controlled access to certain fishery resources. Protected areas can be seen as one of the tools fishery managers use to control the extent of exploitation in fisheries. However, as protected areas are a ‘blunt’ policy instrument, in the sense that they do not alter the market incentives of individual operators, the economic outcome from their use will be sensitive to the other controls in place in the fishery.

Marine protected areas are also believed to provide a hedge against uncertain events and normal population fluctuations through preservation of environmental processes and biomass (Lauck *et al.* 1998). Bioeconomic modeling of fisheries has shown that protected areas can increase yields when stock levels are low (Pezzey *et al.* 2000, Sanchirico and Wilen 2001, and Greenville and MacAulay 2004), reduce harvest variation for a single biomass (Conrad 1999, Pezzey *et al.* 2000 and Hannesson 2002), but have the potential to increase harvest variation in a multi-species environment (Greenville and MacAulay 2005). The purpose of this paper is to examine the performance of marine protected areas used as a tool for fishery management in a two-species, two-patch fishery. The model will be applied to the NSW fishing industry located in the Manning Bioregion, with focus placed on the biological characteristics that are required for protected area use to improve the resource rent in the fisheries examined.

2. MARINE PROTECTED AREAS

Marine parks were established in NSW via the *Marine Parks Act 1997*. The purpose of establishment is to preserve the biodiversity and ecological functioning, of the NSW marine environment. As such, the use of marine parks in NSW has not been directed as a tool for fisheries management, instead the parks have been set up to achieve certain conservation outcomes. The question of whether these parks can achieve their desired conservation outcome is not the purpose of this paper; instead, the aim of this paper is to test the performance of protected areas (defined as a no-take zone) if they were to be used as a tool for fisheries management.

Results obtained from the bioeconomic analysis of marine protected areas used as a tool for fisheries management vary. Protected areas used in open access fisheries exploiting single stocks have been shown to potentially lead to some gain for both fishers and society (Sanchirico and Wilen 2001). Despite this, it has been suggested that in these circumstances, the ability of protected areas to achieve its conservation objective is questionable as the concentration of effort in the remaining area could offset a conservation outcome (Hannesson 2002).

Conrad (1999) observed two possible benefits from the creation of a marine protected area. First, the creation of the protected area could reduce the overall variation in biomass and as such harvest; and second, it may reduce the costs of management mistakes. Similar results were found by Hannesson (2002) who found that average catch increased, with variation in these catches decreasing. Under open access, the reduced variation in catch was argued to represent an economic gain from the establishment of a protected area (Hannesson 2002). Hannesson (2002) suggested that reduced variation in catch was due primarily to the migration effect, with the instances where the biomass falls such that it is un-economic to fish reduced.

The effect of protected area establishment on harvests and resource rent was further explored by Grafton *et al.* (2004,2005) and Greenville and MacAulay (2005). Grafton *et al.* (2004) examine the performance of a marine protected area in a fishery characterized by environmental stochasticity and the presence of an uncertain negative shock. The fishery was assumed to be comprised of a single biomass, with a uni-directional flow of biomass between protected area and fishery. The flow of biomass was driven by differences in relative population densities. Grafton *et al.* (2004) found the establishment of a protected area reduced the effects of the negative shocks on the fishery, effectively smoothing the harvest of biomass, improving the resource rent generated in the fishery. Grafton *et al.* (2005) further state that whilst the use of protected areas will not guarantee against a population collapse, they can generate economic benefits through the buffer effect of higher stocks.

Similar results were obtained by Greenville and MacAulay (2005) who found that the establishment of protected areas in a multi-species fishery, open to uncertain stock collapse events, improved the level of resource rent Resource rent was improved even under optimal management for certain sized protected areas. Given sub-optimal management, larger protected areas were required to maximize the resource rent generated in the fishery.

3. THE STOCHASTIC BIOECONOMIC MODEL

The approach used in this study follows the model outlined by Greenville and MacAulay (2005). Formally, the model sets out the exploitation of a fishery comprised of two-species interacting under a predator-prey relationship. The species occur within two sub-populations within the fishery (although further populations can be added without introducing much extra complexity) and migrate between the patches according to relative densities. Two cases of density-driven dependent dispersal are examined in this paper. First, when feedback is allowed and dispersal occurs based on differences in relative densities (density-dependent); and second, where there is no feedback and dispersal represents a uni-directional flow out of the protected area (sink-source).

Harvest in the fishery is assumed to following a Schaefer (1957) production function with a constant per unit of effort cost (*c*). The Schafer production function is represented by $h_i^j=q_i^jE_i^jJ_i^j$ where h_i^j is the level of harvest of species j in patch i, q_i^j the catchability coefficient of species j in patch i, E_i^j the level of effort applied to species j in patch i, and J_i^j the level of biomass of species j in patch i (Greenville and MacAulay 2005). The equations of motion which represent the change in biomass over time are represented by equations (1) and (2), with X_i the prey species and Y_i the predator species (Greenville and MacAulay 2005)

$$\dot{X}_i = X_i\left[r\left(1-\frac{X_i}{K_i}\right)-aY_i\right]+z_i^x-q_i^xE_i^xX_i \tag{1}$$

$$\dot{Y}_i = Y_i\left[s\left(1-\frac{bY_i}{X_i}\right)\right]+z_i^y-q_i^yE_i^yY_i \tag{2}$$

where r is the intrinsic growth rate, K_i the carrying capacity of patch i, a and b the predation parameters (assumed to be greater than zero), z_i^x and z_i^y are the dispersal relations and all other variables as defined. The dispersal patterns are given in equations (3) for density dependent taking prey species as an example, and (4) for sink-source depicting as the flow from the source patch taking predator species as the example (flow into the sink patch has a positive coefficient).

$$z_i^x \equiv g^x\left(\frac{X_j}{K_j}-\frac{X_i}{K_i}\right) \tag{3}$$

$$z_i^y \equiv -g^y\left(\frac{bY_i}{X_i}\right) \tag{4}$$

4. THE MANNING BIOREGION

In 2004, an assessment of the Manning Self Bioregion, which spans north of the Hunter river to north of Nambucca Heads, was completed and identified an area between Stockton Beach and Wallis Lake as the likely area for a new marine park (Breen *et al.* 2004 p.105).

The proposed site for the new marine park lies within NSW Department of Primary Industries (DPI) reporting regions of Ocean Zone 5 and Estuary Region 4. Currently, 7 wild-harvest marine fisheries in operation are commercially fished in the proposed parks boundaries. Of the 6 fisheries to which data was obtained, the Ocean Trap and Line fishery is the most valuable, with average gross revenue of \$4.9 million from 1997/98 to 2003/04. In some fisheries, there has been a notable reduction in catch and value (specifically the Fish Trawl and Ocean Prawn trawl Fisheries). It is unknown as to whether these declines have been caused by normal seasonal variations in stocks and weather (such as droughts), or are representative of a decline in the resource base.

For the purpose of the study, two fisheries were isolated to examine the possible effects of protected area creation. The Ocean Trap and Line and Ocean Prawn Trawl fisheries were chosen for the case study as they provide the best examples of fisheries which predominantly harvest predator and prey species respectively. For the Ocean Prawn Trawl fishery, the top 5 species targeted comprise 82 percent of average total fishery catch from 1997/98-2003/04, with 63 percent for the Ocean Trap and Line fishery.

5. MODEL CALIBRATION

Data on catch, value and effort was obtained from the NSW DPI. Data on catch and effort for the two fisheries, Ocean Prawn Trawl (the prey fishery), and Ocean Trap and Line (the predator fishery) per month from July 1997 to June 2004 (84 observations) was used to calibrate the model. Catch per unit effort is often used as proxy for biomass levels as it provides an indication of the productivity of the underlying biomass (Kirkley *et* *al.* 2002) and was used as a proxy for biomass in this study. Whilst catch per unit effort does not directly measure biomass levels, it does provide some information as to the stock productivity in that area (Kirkley *et al.* 2002).

Estimates for the bioeconomic model will be used to test the performance of marine protected areas in the Manning Bioregion. The model is estimated at a fishery level with dynamics expected to take effect post protected area establishment. Catch per unit effort for prey and predator species are used as the estimates for prey (X) and predator (Y) biomass. Assuming the fishery is in steady state, equations (1) and (2) will be equal to zero, a relationship between catch and growth (assumed to equal harvest) defined in equations (3) and (4):

$$h(X) = rX - \frac{rX^2}{K} - aXY \tag{3}$$

$$h(Y) = sY - \frac{sbY^2}{X} \tag{4}$$

where $h(X)$ and $h(Y)$ are harvest of prey and predator species respectively. Linear regression techniques cannot be used to obtain estimates of these equations directly. As such, these equations are ‘reduced’ into linear form. The linear reductions of equations (3) and (4) augmented by a constant term (c_x and c_y respectively) are given by equations (5) and (6) respectively where $\alpha, \beta, \delta, \varphi, \lambda$, and γ are parameters to be estimated. The ε_t^x and ε_t^y terms represent an error term assumed to be independent and identically normally distributed for prey and predator species respectively. Both models were augmented with a constant to prevent bias in the regression estimates. The W term is used to represent weather effects on the prey biomass, and is equal to monthly rainfall recorded at Nelson Bay, located within Estuary Region 4 and Ocean Zone 5, and centre of much of the fishing activity in the region. Weather is believed to influence the level of biomass for prey species, in particular prawns, through the influence on fresh water and nutrient flow into estuaries where these species initially grow.

$$h(X_t) = c_x + \alpha X_t - \beta X_t^2 - \delta XY_{t-4} + \varphi W_{t-1} + \varepsilon_t^x \tag{5}$$

$$h(Y_t) = \lambda Y_t - \gamma \frac{Y_t^2}{X_t} + \varepsilon_t^y \tag{6}$$

As can be seen from equations (5) and (6), the parameter values for b and K cannot be directly estimated. An estimate of K can be obtained from α/β following equation (3) and represents the point where growth is equal to zero (either biomass equal to zero or K). Similarly, an estimate of b is obtained from γ/λ following equation (4).

Estimates of the parameters were found and are given in Table 1. The predation effect on the growth of prey biomass was lagged four periods as this represented the best fit for the data. This suggests that the effect that predation has on harvests and biomass growth in this period will reduced the spawning biomass in four months time and not have an instantaneous effect on current growth or harvests.

Table 1: Parameter Estimates

Coefficient	Estimate	t-ratio	Parameter	Value
α	0.416	3.01	r	0.416
β	-0.007	-1.366	K	58.830
δ	-0.006	-1.581	a	0.006
φ	0.003	3.861	φ	0.003
λ	0.518	8.102	s	0.518
γ	-0.053	-0.766	b	0.102

The estimate for the intrinsic growth rate s in the predator model was significant at a 5 percent level of significance. Despite this, the estimate of the γ coefficient was not significant, but was included due to its relevance. The adjusted R squared value was equal to 0.6861 with inconclusive results from hypothesis tests for autocorrelation. Dicky-Fuller tests for unit roots were conducted on the variables, with results being not inconsistent with the data having a stationary mean.

The estimate of the b parameter for the predator model was found to be less than 1. As such, in this system there is a potential for predator numbers to be greater than prey numbers. The reason for this result is believed to be due to the fact that the predator species caught in the Ocean Trap and Line Fishery do not exclusively freed on the species caught in the Ocean Prawn Trawl Fishery. As such, there is an implicitly assumption behind the results from the model that once a marine protected area is established, other food sources for the predator species also increase within the protected areas boundaries to be sufficient to provide suitable carrying capacity for the population levels.

For the prey model, all parameter values had expected signs. The adjusted R-squared for the model was equal to 0.5762; however, a Durbin-Watson test conducted on the error term confirmed the model suffered from autocorrelation. As for the predator model, a unit root test was conducted with the results not inconsistent with the data having a stationary mean. Estimates for the parameters corrected for autocorrelation (via the Cochrane-Orcutt procedure) were obtained and are reported in Table 1 (adjusted R-squared of 0.7251). Once this correction was made, the β coefficient was statistically insignificant.

From the estimation, distributions for the growth rates, weather and the correlation between the species can be obtained. The distribution for the weather term is derived from the observations of monthly rainfall at Nelson Bay from January 1882 to March 2005. Rainfall was found to be distributed under a Weibull distribution with mean 112 and standard deviation 88. Distributions for the growth rates were taken from the error terms from the fitted regressions in equations (5) and (6). For prey, the intrinsic growth rate was found to be distributed under an Extreme Value distribution with mean 0.43 and standard deviation 0.14. The predator intrinsic growth distribution was found to be normal with mean 0.52 and standard deviation 0.06.

The correlation between the growth rates of the two populations was taken from the correlation between the two error terms from the estimated regressions. The correlation was found to be equal to 0.53. Prices received for the two species were taken as the average unit value of catch over the period from 1997/98 to 2003/04. The average price of prey species was found to be \$8 per kg and for predator species \$4.75 per kg. On the production side, information on the cost of effort is not know, and as such was found by solving for the level of cost that gave rise to the current harvests given biomass and other parameter estimates. The cost figures determined assume that no resource rent is being generated in the fishery through current controls on fishing pressure. Due to input controls being used in the fishery, this result is possible; however, it is likely that some rent, although marginal, may be generated in the fishery. Further, this rent has the potential to continue as management controls are improved overtime to maintain current harvests and limit fishers from substituting uncontrolled for controlled inputs thus dissipating any rents generated.

An economic survey of commercial fishers in 1999/00 was commissioned by NSW DPI to provide some information about the total return to fishers from their operations in NSW fisheries. This cost and revenue data (NSW Department of Primary Industries 2004) was used to estimate potential rent in the fisheries. From the data, it is estimated that levels of resource rent generated in the Ocean Prawn Trawl Fishery was equal to 8 percent of total costs. For the Ocean Trap and Line Fishery, the data is yet to be released and as such, the rent generated was assumed to be the same as for the Ocean Prawn Trawl Fishery. The estimates were used to compute cost per unit of effort for prey species equal to \$133 per day fished and \$69 for predator species (based on average days fished over the 1997/98 to 2003/04 period).

6. SIMULATION RESULTS

Simulation of the model was done using @Risk 4.1. For each protected area size, 10,000 draws were taken from the 5 random distributions to yield steady-state catch, biomass and rent for the two fisheries.

6.1. Density-Dependent Dispersal

Changes in resource rent levels generated in the fishery post protected area establishment are sensitive to the level of dispersal that occurs. The greater the migration away from the reserve, the greater the potential benefit from protected area establishment. Further, different sized marine protected area yield different results in terms of mean steady-state harvests, biomass and rent. For brevity, protected areas are classified into groups; small sized protected areas, which are equal to 15 to 30 percent of the total fishing grounds; medium sized protected areas, which are equal to 35 to 50 percent of the total fishing grounds; and, large sized protected areas, which are greater than 55 percent of the total fishing grounds.

The establishment of a protected area in the Manning Bioregion has different effects on the predator and prey species. Total prey numbers in the fishery fell for small to medium sized protected areas, leading to a reduction in prey harvests in both the fishery and remaining fishing ground. This fall was due to the increase in predator numbers within the fishery. Total predator numbers increased for all protected areas sizes, increasing both harvests and the level of predation. This effect can be seen as ‘restoring the balance’ in population numbers. As predator numbers are relatively low compared with no-harvest levels, the increase in predator numbers is significant limiting the benefit of protected area creation to the prey species fishery and improving the benefit for the predator species fishery. This result can be seen for total mean harvests, which decreased for prey species for most sized protected areas, and increased for predator species.

The net social cost, in terms of forgone resource rent (total for both fisheries) is depicted in Figure 2. For all dispersal levels, a slight diminishing cost to protected area establishment can be seen, until very large protected areas are established. The reason for the uniform result at the extreme was due to the fact that the fishing ground becomes very small, and the maintenance of a sub-population that contains both species becomes difficult. From Figure 2, for g equal to 3, an optimal sized protected area exists close to 15 percent of the total fishery; this increases to 20 percent when *g* is equal to 4.

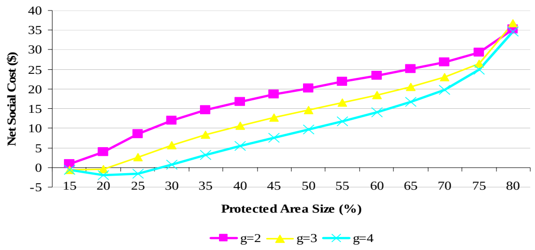

Figure 2: Net social cost with density-dependent dispersal.

With the decreased total resource rent in the area, the variation of this rent also decreased. This result was also seen in the variation of mean harvest levels which also decreased for most sized protected areas. This hedge effect was lessened with increased dispersal. The reason for this is that with increased dispersal (as *g* increases), the reliance of harvests on dispersal also increases. As dispersal is analogous to an excess supply of biomass from the protected area (determined by within patch levels of prey and predator biomass), it is more variable that harvesting the underlying resource itself (despite reducing periods of low harvests), making total harvests more variable. This effect was seen for predator species but not for prey species. In the remaining fishing grounds, small sized protected areas lead to a decrease in the variation of mean harvests. The decreased variation can be seen as an offset to the lost aggregate mean catch for prey species, and a 'double gain' in terms of predator species.

6.2. Sink-Source Dispersal

Under sink-source dispersal, the ability for the protected area to yield a net benefit to the fishery was less than seen for density dependent. For dispersal rate *g* equal to 2 and 3, the protected area did not yield any benefits to the fishery in terms of an increase in mean steady-state resource rent. As was seen under density-dependent dispersal, the creation of the protected area reduced the mean steady-state level of prey biomass in the fishery for small to medium sized protected areas. Given this, mean steady-state harvests also fell for both the fishery and the remaining fishing ground. As was seen for density-dependent dispersal, mean steady-state predator biomass and harvests also increased post protected area creation.

The net social cost from protected area establishment in given in Figure 3. Unlike density-dependent dispersal, a minimum sized protected area was required to obtain a net benefit (shown by the negative region of the costs curve) from protected area creation. Under high dispersal levels, when *g* was equal to 4, the establishment of a protected area of 25 percent of the fishery maximized the resource rent generated. Despite this, for lower dispersal rates, any sized protected area did not yield an increase in the resource rent generated. The reason for lesser benefits from smaller protected areas under sink-source dispersal was because of the difference in the dispersal drivers.

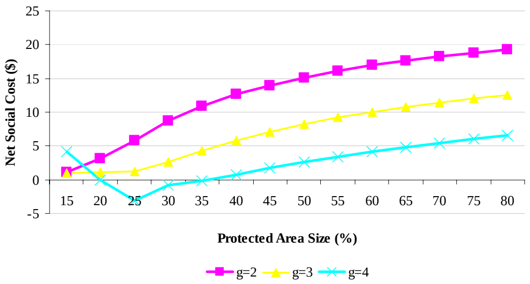

Figure 3: Net social cost with sin-source dispersal.

Variation in mean steady-state total rent from the fisheries increased for some small sized protected areas. When *g* was equal to 4, the increase in mean steady-state rent was accompanied by an increase in variation, resulting from a reliance on a more variable flow of predator stocks from the protected area. However, for larger sized protected areas, variation in resource rents decreased, indicating that they can be used as a hedge against normal fishery variation The variation of mean steady state predator harvest increased, with mean steady-state harvests in the prey fishery decreasing for most sized protected areas. The increase in mean harvest variation for the fisheries was also seen in the open fishing grounds, which, due to increased reliance on the dispersal flow, become more variable.

7. CONCLUSIONS

The results under the assumption homogenous catch show that protected area can be used as a fisheries management tool in the Manning Bioregion under certain conditions. Both the nature and extent of the dispersal from the protected area are key features in determining the economic outcome from protected area creation. The greater the level of dispersal, the greater the benefits from protected area establishment as more of the biomass that occurs within the protected area is likely to flow to the surrounding fishery. As large differences in relative densities occur irrespective of the size when protected areas established, the value of small sized protected areas is enhanced through density-dependent flows. Under sink-source flows, differences in relative densities do not encourage increased flows from the protected areas, making the level of dispersal more dependent on protected area size. Given this, when sink-source flows are likely, a minimum size protected area is required before benefits to the fishery can be obtained.

The creation of a marine protected area in the Manning Bioregion is likely to have different distributional effects on the two fisheries examined in this paper. For the prey fishery, the Ocean Prawn Trawl Fishery, the benefits of protected area creation are limited by the effects of predation. As such, the protected area is less likely to increase harvests and fishery rent post establishment. Further, certain sized protected areas increased the variability of harvests, meaning that overall harvests were not only reduced but more variable. The counter occurred for the predator fishery, the Ocean Trap and Line Fishery, which is more likely to benefit from protected area creation as increased prey and the removal of fishing pressure increased the biomass of these species in the fishery. Despite the potential gain, in the open fishing grounds harvests of these species is likely to become more variable.

For the two fisheries as a whole, the creation certain sized protected areas can yield some hedge benefits in terms of overall harvests and resource rent. However, for this to occur, a minimum size is required. Small sized protected areas are less likely to yield hedge benefits to the fishery, with medium to large more likely. The reason for this is that smaller sized protected areas do not increase biomass greatly above exploited levels, reducing the ability for biomass in the protected area to reduce normal fluctuations in populations caused through environmental stochasticity.

Protected areas have the potential to become a useful tool for the management of fisheries. However, the effects of protected areas are likely to have differing effects on fisheries that target different species. For the Manning Bioregion, two fisheries were examined in isolation, as such; the full effect on all the fisheries that operate in that region is unknown. Despite this, results from the model show that benefits in the form of improved resource rent and reduced harvest variation are possible. These results are conditional on the maintenance of current resource rent levels in the fishery. As input controls are exclusively used in the fishery, there is a strong possibility that any resource rent will be lost due to competitive behavior resulting in increased investment and as such cost in the fishery. Given this, it is important for fishery managers to ensure the current mix of controls are not only achieving sustainable harvest levels, but maximizing the resource rent generated in the fishery.

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