

Marine Protected Areas in Fisheries Management

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1. Introduction

Marine protected areas can be used in fisheries to manage the activities of individuals on a spatial scale. The use of marine protected areas has been advocated to overcome some of the problems that arise from non-spatial controls. However, as protected areas 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 believed to provide a hedge against uncertain events and population fluctuations through preservation of environmental processes and biomass (Lauck et al. 1998). Bioeconomic modelling of fisheries has shown 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 two-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.

2. Marine Protected Areas

The use of marine parks in NSW has not been directed as a tool for fisheries management, instead the parks have been used to achieve conservation outcomes. The question of whether these parks can achieve desired conservation outcomes is not

examined; instead, the performance of protected areas (defined as a no-take zone) if they were to be used as a tool for fisheries management is explored.

Protected areas used in single-stock open access fisheries have been shown to potentially lead to a gain for both fishers and society (Sanchirico and Wilen 2001). However, it has been suggested that in these circumstances, the protected areas conservation outcome is questionable due to a concentration of effort in the remaining area (Hannesson 2002).

Conrad (1999) observed two benefits from a protected area. First, the area could reduce the overall variation in biomass and harvest; and second, it may reduce the costs of management mistakes. Hannesson (2002) found similar results, with an increase in the average catch, the variation of this catch fell. Under open access, the reduced variation in catch was argued to represent an economic gain. Hannesson (2002) suggested that reduced variation in catch was due primarily to the migration effect, with the instances where biomass falls such that it is un-economic to fish reduced.

The effect of protected area on harvests and resource rent was explored by Grafton et al. (2004,2005) and Greenville and MacAulay (2005). Grafton et al. (2004) examine the performance of a protected area in a fishery with environmental stochasticity and an uncertain negative shock. The fishery was assumed to comprise a single biomass, with a uni-directional flow of stock between protected area and fishery. Grafton et al. (2004) found that a protected area reduced the effects of the negative shock, effectively smoothing harvest, improving the resource rent. Grafton et al. (2005) state,

that whilst the use of protected areas will not guarantee against a population collapse, it can generate economic benefits through the buffer effect of higher stocks. Similar results were obtained by Greenville and MacAulay (2005). The establishment of protected areas in a two-species fishery, open to uncertain stock collapse events, improved the level of resource rent under both sub and optimal management.

3. The Stochastic Bioeconomic Model

The approach follows the model outlined by Greenville and MacAulay (2005). The model sets out a fishery comprised of two-species interacting under a predator-prey relationship. The species occur within two sub-populations within the fishery and migrate between the patches according to relative densities. Two cases of density-driven dependent dispersal are examined. 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 from the protected area (sink-source).

Harvest in the fishery is assumed to following a Schaefer (1957) production function with a constant per unit cost (c) of effort. The production function is represented by $h_i^j = q_i^j E_i^j J_i^j$ 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 represented by equations (1) and (2), with X_i the prey species and Y_i the predator species in patch i (Greenville and MacAulay 2005):

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

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

where r is the intrinsic growth rate, K_i the carrying capacity of patch i , a and b the predation parameters ($a, b > 0$), z_i^x and z_i^y are the dispersal relations and all other variables as defined. The dispersal patterns are given in equation (3) for density dependent (prey species as the example), and (4) for sink-source depicting as the flow from the source patch (predator species as the example with flow into the sink patch being positive).

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

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

4. The Manning Bioregion

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

Seven wild-harvest marine fisheries are in operation in the proposed parks boundaries. In some fisheries, there has been a notable reduction in catch (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. The Ocean Trap and Line and Ocean Prawn Trawl fisheries were chosen for the case study as they provide the best examples of fisheries that 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

Monthly data on catch, value and effort from July 1997 to June 2004 (obtained from the NSW Department of Primary Industries) for the two fisheries, Ocean Prawn Trawl (the prey fishery), and Ocean Trap and Line (the predator fishery) was used to calibrate the model. Catch per unit effort was often used as proxy for biomass as it provides an indication of the productivity of the underlying biomass (Kirkley et al. 2002).

The model was estimated at a fishery level with dynamics to take effect post protected area establishment. Assuming the fishery is in steady state, equations (1) and (2) will equal zero, with the relationship between catch, growth and harvest defined in equations (5) and (6):

$$h(X) = rX - \frac{rX^2}{K} - aXY \quad (5)$$

$$h(Y) = sY - \frac{sbY^2}{X} \quad (6)$$

where $h(X)$ and $h(Y)$ are harvest of prey and predator species respectively. As linear regression techniques cannot be used to obtain estimates of these equations directly, the equations were ‘reduced’ into linear form. The linear reductions of equations (5) and (6) augmented by a constant term (c_x and c_y to prevent bias) are given by equations (7) and (8) where α , β , δ , ϕ , λ , and γ are parameters to be estimated. The ε_t^x and ε_t^y terms represent error terms assumed to be independent and identically normally distributed. The W term is used to represent weather effects on the prey biomass, equal to monthly rainfall recorded at Nelson Bay, at the centre of much of the fishing activity. 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.

$$h(X_t) = c_x + \alpha X_t - \beta X_t^2 - \delta X Y_{t-4} + \phi W_{t-1} + \varepsilon_t^x \quad (7)$$

$$h(Y_t) = \lambda Y_t - \gamma \frac{Y_t^2}{X_t} + \varepsilon_t^y \quad (8)$$

From equations (7) and (8), the parameter values for b and K cannot be directly estimated. The estimate of K is recovered from α/β following equation (5). The estimate of b is recovered from γ/λ following equation (6). The predation effect on the growth of prey biomass was lagged four periods as this represented the best fit for the data. Estimates of the parameters are given in Table 1.

For the predator model, the estimate of the γ coefficient was not significant, but was included due to relevance. Hypothesis test results for autocorrelation were inconclusive and Dicky-Fuller tests for unit roots were 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 one, meaning there is a potential for predator biomass to exceed prey biomass. This result is believed to be due to the predator species not exclusively feeding on the prey species. There is an implicit assumption in the model that once a protected area is established, other food sources for the predator species also increase within the protected area to be sufficient to provide suitable carrying capacity for the population levels.

For the prey model, all parameter values had expected signs. The Durbin-Watson test conducted on the error term confirmed the existence of autocorrelation. A unit root test was conducted with results not inconsistent with the data having a stationary mean. Estimates for the parameters corrected for autocorrelation (via the Cochrane-Orcutt procedure) are reported in Table 1. Once this correction was made, the β coefficient was statistically insignificant.

Distributions for the growth rates, weather and the correlation between the species were obtained from the estimation and data. 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 regressions. 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, and 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 was \$8/kg and for predator \$4.75/kg. Information on the cost of effort is not known, and was found by solving for the level of cost that gave the current harvests given biomass and other parameter estimates. Due to input controls being used in the fishery, it is likely that some rent, although marginal, may be generated in the fishery. The rent has the potential to continue as management controls are improved overtime to limit fishers substituting uncontrolled for controlled inputs.

Cost and Revenue data from the economic survey of commercial fishers in 1999/00 (NSW Department of Primary Industries 2004) was used to estimate potential rent in the fisheries. It is estimated that level 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 the rent was assumed to also equal 8 percent. 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 post protected area establishment is sensitive to the level of dispersal. The greater the migration from the reserve, the greater the potential benefit from protected area establishment. Different sized protected areas yielded different results. For brevity, protected areas are classified into groups; small sized, which are equal to 15 to 30 percent of the total fishing grounds; medium sized, which are equal to 35 to 50 percent of the total fishing grounds; and, large sized, which are greater than 55 percent of the total fishing grounds.

The establishment of a protected area had different effects on the predator and prey species. Total mean prey numbers in the fishery fell for small to medium sized protected areas, leading to a reduction in mean prey harvests in both the fishery and remaining fishing ground. This fall was due to the increase in predator numbers within the fishery. Total mean 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.

The net cost in terms of forgone mean resource rent (total for both fisheries) is depicted in Figure 1. For all dispersal levels, a slight diminishing cost to protected area establishment can be seen. From Figure 1, 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.

With the decreased total mean resource rent, the variation of rent also decreased. This was also seen in the variation of mean harvest levels, which decreased for most sized protected areas. This hedge effect was lessened with increased dispersal. With increased dispersal (as g increases), the reliance of harvests on dispersal also increased. As dispersal is analogous to an excess supply of biomass (determined by within patch levels of prey and predator biomass), it is more variable than harvesting the underlying resource itself (despite reducing periods of low harvests), making total harvests more variable. 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 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 increased mean steady-state resource rent. The creation of small to medium sized protected area reduced the mean steady-state level of prey biomass. Mean steady-state prey harvests also fell for both the fishery and the remaining fishing ground. However, mean steady-state predator biomass and harvests increased post protected area creation.

The net cost from protected area establishment is given in Figure 2. A minimum sized protected area was required to obtain a net benefit 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. For lower dispersal

rates, any sized protected area did not yield an increase in the resource rent. The reason for lesser benefits from smaller protected areas under sink-source dispersal was because of the difference in the dispersal drivers.

Variation in mean steady-state total rent from the fisheries increased for small sized protected areas. When g was equal to 4, the increase in mean steady-state rent was accompanied by an increase in variation. 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 prey harvest variation.

7. Conclusions

From the results, given homogenous growth, protected areas can be used as a fisheries management tool. 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 (especially for predators) 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.

The creation of a marine protected area in the Manning Bioregion is likely to have different distributional effects on the two fisheries examined. For the prey fishery, the Ocean Prawn Trawl, the benefits of protected area creation are limited by the effects of predation. 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, which is more likely to benefit from protected area creation. 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. 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. 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. From the results, 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. As input controls are exclusively used in the

fishery, there is a strong possibility that any resource rent will be lost due to competitive behaviour resulting in increased investment. It is important for fishery managers to ensure the current mix of controls are not only achieving sustainable harvest levels, but also maximizing resource rent.

8. References

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Table 1: Parameter Estimates

Coefficient	Estimate	t-ratio	Corrected		Parameter	Estimate	Corrected Estimate
			Estimate	t-ratio			
Prey							
α	0.697	3.456 ***	0.416	3.010 ***	r	0.697	0.416
β	-0.015	-1.977 ***	-0.007	-1.366	K	47.599	58.830
δ	-0.011	-2.429 ***	-0.006	-1.581 *	a	0.011	0.006
φ	0.004	3.626 ***	0.003	3.861 ***	φ	0.004	0.003
Predator							
λ	0.518	8.102 ***	n.a		s	0.518	n.a
γ	-0.053	-0.766	n.a		b	0.102	n.a

***Significant at 5 percent, ** Significant at 5 percent, and *Significant at 15 percent. Prey adjusted $R^2=0.5762$ (corrected 0.7251), predator adjusted $R^2=0.6861$, $n=84$.

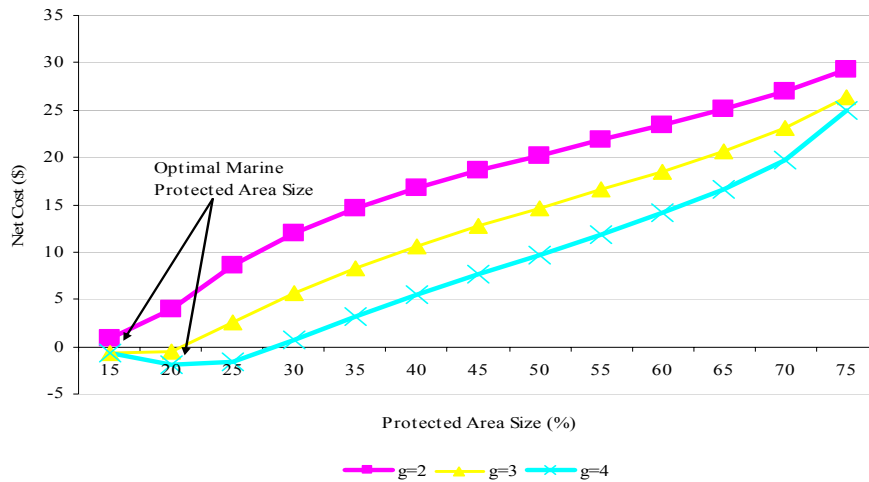


Figure 1: Net social cost with density-dependent dispersal.

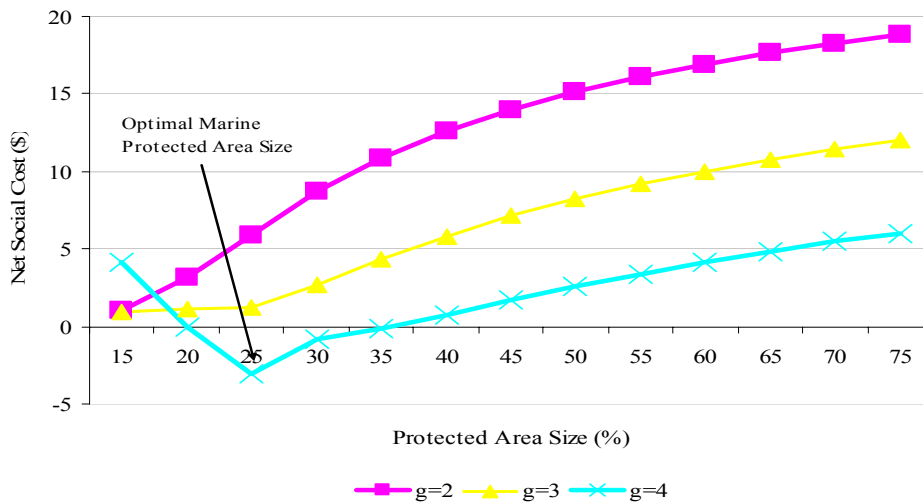


Figure 2: Net social cost with sin-source dispersal.