A Bioeconomic Analysis of Protected Area use in Fisheries Management

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A Bioeconomic Analysis of Protected Area use in Fisheries Management

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Abstract
The use of protected areas as a fishery management tool has been suggested as a hedge against management failures and variation in harvests. A stochastic bioeconomic model of a two-species fishery will be used to test the performance of protected areas as a management tool in a fishery with heterogenous environments. Protected areas are analysed under density-dependent and sink-source dispersal relationships between environments within the fishery. Differing levels of management control over fishery resource extraction are analysed. The model is applied to Manning Bioregion in NSW. The focus of the study is placed on the biological and institutional characteristics that yield benefits to the fishery.

Keywords: Fisheries management, bioeconomics, marine protected areas

1. Introduction

Marine protected areas are a spatial management control used to manage the activities of individuals. Developments in fishing technology have meant that fishers are able to target species on a finer scale, potentially increasing the pressure on stock. This increased pressure has implications for the biological and economic outcomes from wild harvest fisheries. 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 therefore be sensitive to the other controls in place in the fishery.

Marine protected areas have been suggested as a means to manage uncertain events which can cause fisheries to collapse (Grafton and Kompas 2005). Grafton *et al.* (2005) provide examples of 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 benefits occur as stocks within protected areas have the potential to provide a buffer source for the surrounding fishery (Lauck *et al.* 1998).

The purpose of this paper is to examine the performance of marine protected areas as a tool for fishery management in a two-species fishery. A stochastic bioeconomic model of a two-species fishery is used under differing assumptions of fishery environments and management. The model will be applied to the NSW fishing industry located in the Manning Bioregion Australia, with focus placed on the characteristics required for protected area use to improve the resource rent generated in the fishery.

The remainder of this paper is organised as follows. In Section 2, the arguments for marine protected area use in fisheries management are provided, with the bioeconomic model used to test protected area creation discussed in Section 3. An overview of the commercial fishing industry in part of the Manning bioregion is provided in Section 4. Model calibration and results are provided in Sections 5 and 6 with a discussion of the policy implications and concluding comments in Sections 7 and 8.

2. Marine Protected Areas

Results obtained from the bioeconomic analysis of marine protected areas 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 2000). If increases in biomass are seen as a gain to conservationists, and increases in harvests 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. Some authors have suggested that in these circumstances, the ability of protected areas to achieve their conservation objective is questionable due to a concentration of effort in the remaining area (Hannesson 2002).

Under limited entry conditions, Sanchirico and Wilen (2000) argue that the establishment of a protected area would require policy makers to reduce the overall level of effort expended if restrictions above open access effort levels existed. Sanchirico (2005) suggests in a multi-patch fishery, the loss would be minimised with the closure of multiple patches. Despite this, Greenville and MacAulay (2004) showed that some restriction on effort through the use of a tax on effort could yield positive changes in total effort and harvest post the establishment of a protected area.

Conrad (1999) analysed the effect of establishing a protected area in a homogenous environment under open access conditions. Conrad (1999) observed two benefits; first, the creation of the protected area could reduce the overall variation in biomass; and second, it may reduce the costs of management mistakes. However, the hedge benefit occurred for fairly large protected areas (around 60 percent of the fishery). Similar results were found by Hannesson (2002) who found that with one area closed the average catch increased, with variation in these catches decreasing. Hannesson (2002) suggested that reduced variation in catch was due primarily to the migration effect, with the chances and instances where the biomass falls to the extent that it is un-economic to fish reduced. This result did not hold for a fishery with either very high or very low cost of effort (Hannesson 2002).

The effect of protected area establishment on variability in harvests and resource rent was further explored by Grafton *et al.* (2004, 2005) and Greenville and MacAulay (2005). Grafton *et al.* (2004) examined protected areas in a fishery characterised 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. Using a dynamic simulation model, Grafton *et al.* (2004) found the establishment of a protected area reduced the effects of negative shocks on the fishery, effectively smoothing harvest and improving resource rent for small sized protected areas (around 20 percent of the fishery). Grafton *et al.* (2005) state, whilst the use of protected areas will not guarantee against a population collapse, they can generate economic benefits through the buffer effect of stocks in the protected area.

3. The Stochastic Bioeconomic Model

Bioeconomic models have been used to evaluate the use of marine protected areas as a tool for fisheries management by various authors (Hannesson 1998, 2002, Sumaila 1998, Conrad 1999, Pezzey *et al.* 2000, Sanchirico and Wilen 2000, 2001, Anderson 2002, Grafton *et al.* 2004, Greenville and MacAulay 2004, Greenville and MacAulay 2005 and Grafton *et al.* 2005a and many others). The approach used in this study follows the model outlined by Greenville and MacAulay (2005).

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 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 is by a uni-directional flow (sink-source).

Harvest in the fishery is assumed to follow a Schaefer (1957) production function with a constant per unit cost of effort (*c*). The Schaefer 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 are given in equations (1) and (2), with X_i the prey species and Y_i the predator species (Greenville and MacAulay 2005):

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

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

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 the dispersal relationships and all other variables as defined. The dispersal patterns are given in equations (3) for density-dependent with prey species as the example, and (4) for a sink-source flow (source patch) taking predator species as the example (the sink patch has a positive coefficient).

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

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

4. The Manning Bioregion Commercial Fishing Industry

The NSW Government has committed to the establishment of a representative system of marine parks. The aim is to protect elements of the unique marine habitats that span the NSW coast. Although the primary focus for protected area establishment is not as a tool for fisheries management, it is likely to lead to some effects on the NSW commercial fishing industry. However, the likely structure of the park will be different to what is required for use as a management tool (Grafton *et al.* 2005b). In 2004, an assessment of the Manning Shelf Bioregion, which spans north of the Hunter River to north of Nambucca Heads, was completed and identified as an area between Stockton Beach and Wallis Lake as the likely area for a new marine park (Breen *et al.* 2004 p.105).

Currently, 7 wild-harvest fisheries are commercially fished within the proposed parks boundaries. Fishery catch and value for 6 of the fisheries is given in Table 1. Of the 6 fisheries reported, the Estuary General fishery is the most valuable, with average gross revenue of $2.7 million from 1997/98 to 2003/04 based on average monthly Sydney Fish Market prices. In some fisheries, there has been a notable reduction in catch (Fish Trawl and Ocean Prawn trawl fisheries). It is unknown as to whether the declines has been caused by normal seasonal variations in stocks and weather (such as droughts), or are representative of a decline in the resource base.

Table 1: Fishery Catch and Value in the Manning Bioregion

Year		1997/98	1998/99	1999/00	2000/01	2001/02	2002/03	2003/04
	Catch (kgs)	724,774	877,868	751,779	745,620	956,197	753,348	542,682
Estuary General	Value ($)	$ 2,339,685	$ 2,493,831	$ 2,636,075	$ 2,702,355	$ 3,512,826	$ 3,472,571	$ 2,261,472
	Catch (kgs)	568,807	514,648	313,810	247,859	233,577	268,344	192,706
Fish Trawl	Value ($)	$ 1,683,337	$ 1,573,915	$ 1,016,532	$ 847,673	$ 806,414	$ 936,231	$ 612,895
	Catch (kgs)	642,956	398,442	500,819	360,964	541,824	595,726	512,692
Ocean Hauling	Value ($)	$ 1,145,803	$ 738,596	$ 1,012,698	$ 738,425	$ 1,169,483	$ 1,329,103	$ 1,036,055
	Catch (kgs)	334,981	305,509	209,252	247,742	206,803	193,390	120,279
Ocean Prawn Trawl	Value ($)	$ 2,751,469	$ 2,551,777	$ 2,198,750	$ 2,367,728	$ 1,754,945	$ 1,934,599	$ 1,458,876
	Catch (kgs)	237,621	266,320	218,264	146,905	147,436	125,523	130,245
Ocean Trap and Line	Value ($)	$ 968,304	$ 1,089,209	$ 961,551	$ 748,587	$ 760,302	$ 621,475	$ 634,244

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 which predominantly harvest predator and prey species respectively.

5. Model Calibration

Data on catch, value and effort were obtained from the NSW Department of Primary Industries, the government authority responsible for managing fisheries in NSW. In total, there were 84 monthly observations on catch and effort from July 1997 to June 2004. Catch per unit effort was used as proxy for biomass levels as it provides an indication of the productivity of the biomass (Kirkley *et al.* 2002). Whilst catch per unit effort does not directly measure biomass, it does provide some information as to the stock productivity (Felthoven and Paul 2004). Changes in catch per unit effort for the two fisheries are shown in Figure 1. Some dynamics of the stocks can be derived from examining changes in harvests in response to the other variables in the model. A lag of four periods was chosen for the predator-prey interaction as for lags of shorter or longer length; no discernable relationship could be seen.

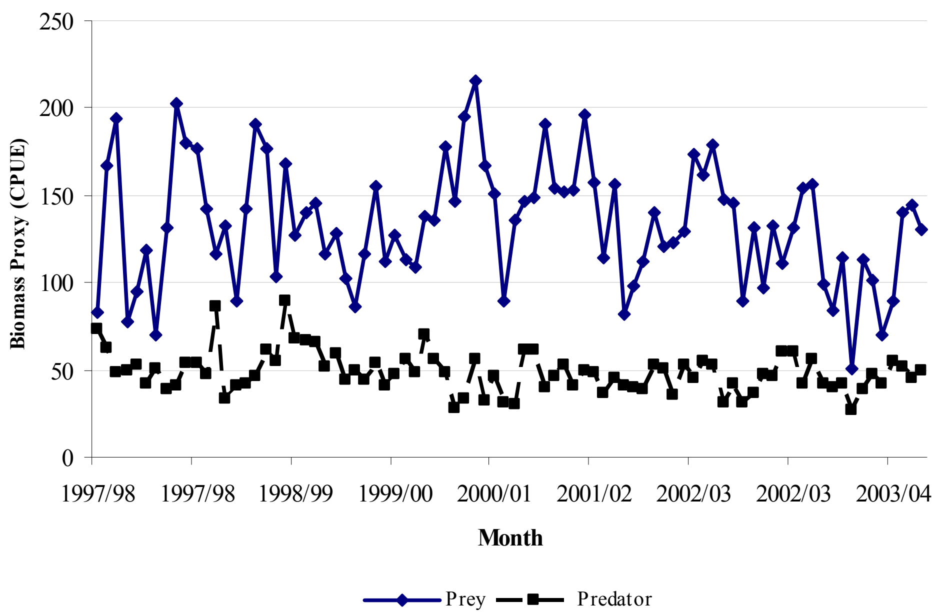


Figure 1: Prey and Predator Catch per Unit Effort

In order to find estimates of the parameters in the bioeconomic model the fishery was assumed to be in a steady-state. Given this, a relationship between catch and growth (assumed to equal harvest) at a fishery level can be defined and is given by equations (5) and (6):

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

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

where $h(X)$ and $h(Y)$ are harvest of prey and predator species respectively. The linear reductions of equations (5) and (6), augmented by a constant term (c_x and c_y respectively) are given by equations (7) and (8) respectively. Coefficients α, β, δ, φ, λ, and γ are to be estimated, with ε_t^x and ε_t^y representing error terms 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_{t-1} term is used to represent weather effects on the prey biomass, and is equal to the monthly rainfall recorded at Nelson Bay located at the centre of much of the fishing activity in the region. Weather is believed to influence the level of biomass for prawn species through its influence on fresh water and nutrient flow into estuaries.

$$h(X_t) = c_x + \alpha X_t - \beta X_t^2 - \delta XY_{t-4} + \varphi W_{t-1} + \varepsilon_t^x \qquad (7)$$

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

The parameter values for b and K (in equations 5 and 6) cannot be directly estimated. An estimate of K can be obtained from α/β following equation (5) 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 (6). Estimates of the parameters were found and are given in Table 2.

Table 2: Parameter Estimates

Coefficient	Estimate	t-ratio	Corrected Estimate	t-ratio	Parameter	Estimate	Corrected Estimate
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, Adjusted R^2 predator=0.6861, Adjusted R^2 corrected prey=0.7251.

Hypothesis tests for autocorrelation in the predator model were not conclusive. Dicky-Fuller tests for unit roots were conducted on the variables, with results being not inconsistent with the data having a stationary mean. A plot of the actual and fitted predator harvests is given in Figure 2.

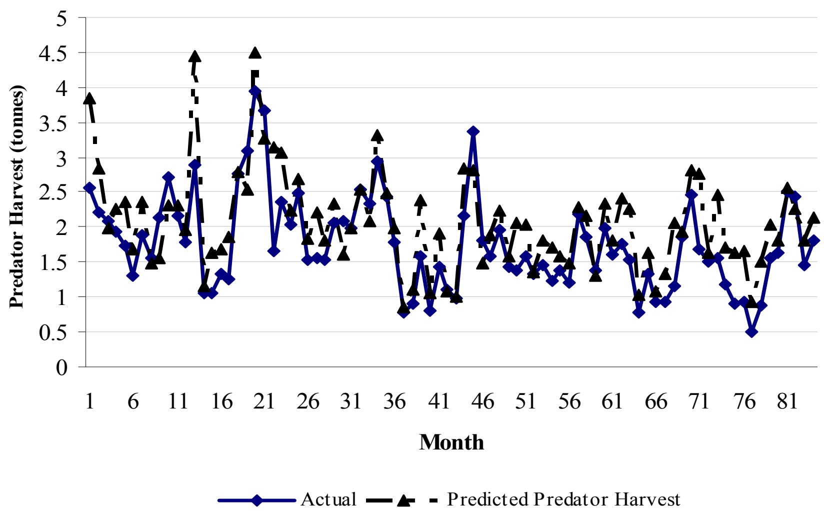


Figure 2: Actual versus Predicted Predator Harvests

The estimate of the *b* parameter for the predator model was found to be less than 1. In this system there is a potential for predator numbers to exceed prey numbers. This result is believed to be due to the fact that the predator species do not exclusively feed on the species in the Ocean Prawn Trawl Fishery. There is an implicit assumption that once a marine protected area is established, other food sources also increase within the protected areas boundaries to be sufficient to provide suitable carrying capacity for the predator population levels.

For the prey model, all parameter values had the expected signs. A Durbin-Watson test confirmed first order autocorrelation. 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) are reported as the 'Corrected Estimates' in Table 2. A plot of the actual and fitted prey harvests is given in Figure 3.

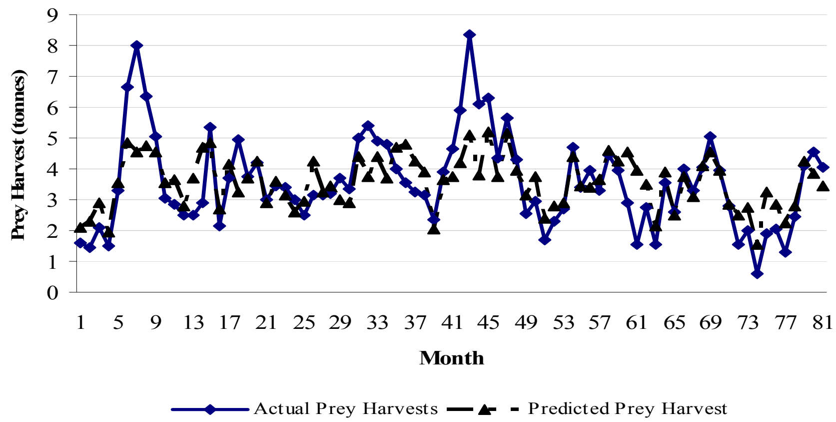
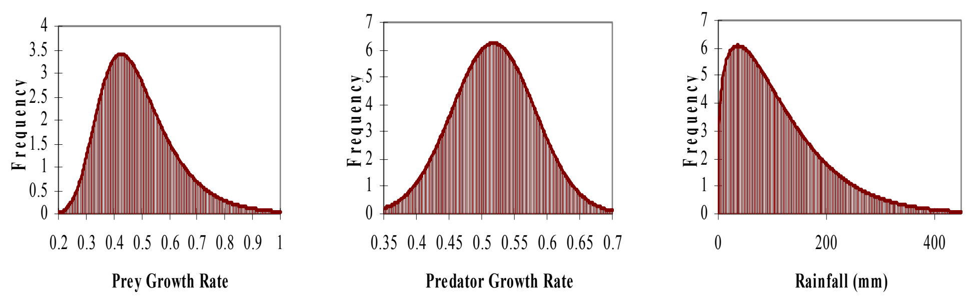


Figure 3: Actual versus Predicted Prey Harvests

From the estimation, distributions for the growth rates, weather and the correlation between the species were obtained. The distributions for *r, s* and *W* are given in Figures 4 (a), (b) and (c) respectively. The distribution for the weather term is derived from monthly observations of rainfall at Nelson Bay from January 1882 to March 2005.

(a) Prey Growth (b) Predator Growth (c) Rainfall



(a) Extreme Value
Mean: 0.43, SD: 0.14

(b) Normal
Mean: 0.52, SD: 0.06

(c) Weibull
Mean: 112, SD: 88

Figure 4: Distributions of Stochastic Parameters

The correlation between the growth rates 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 July 1997 to June 2004 (prey \$8/kg, 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 rise to the current harvests given other parameter estimates. The cost figures need to take into account resource rent. As input controls are used, 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 over time to maintain current harvests and limit fishers from substituting uncontrolled for controlled inputs.

A state-wide economic survey of commercial fishers in 1999/00 was commissioned by the NSW Department of Primary Industries. This cost and revenue data (NSW Department of Primary Industries 2004) were used to estimate the potential rent in the fisheries. It was estimated that levels of resource rent generated in the Ocean Prawn Trawl Fishery were equal to 8 percent of total costs. For the Ocean Trap and Line Fishery, the environmental impact statement is yet to be released, thus the rent generated was assumed to be the same as for the Ocean Prawn Trawl Fishery. Average cost estimates were found to be $133/day and $69/day for the Ocean Prawn Trawl and Ocean Trap and Line fisheries respectively (differences consistent with methods).

6. Simulation Results

For the simulation, several scenarios were examined. The first was when growth was assumed to be homogenous across the patches (Scenario 1). Under the second scenario, the protected area was assumed to be created in areas of greater biological value (Scenario 2). The potential surplus yield in these grounds is greater than that experienced in the open fishing ground per unit of carrying capacity.

For all scenarios, density-dependent and sink-source dispersal relationships were examined with varying levels of migration. As no data on migration of species were available, results from the simulation will be used to find the level of migration that would be required for the marine park to lead to a net economic gain. In addition to this, changes in the current management arrangements were examined (Scenario 3).

Scenario 1: Homogenous Catch

The results for scenario 1 are presented in this section for density-dependent and sink-source dispersal. In general, a small-sized marine protected area of around 15 to 20 percent of the fishery can yield some benefits to society in the form of increased resource rent.

Density-Dependent Dispersal

Changes in mean resource rent generated in the fishery 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. The establishment of a protected area had different effects on the predator and prey species. Total mean prey numbers in the fishery fall for small to medium sized protected areas, leading to an overall reduction in mean prey harvests (both fishery and remaining fishing ground). This fall is due to the increase in mean predator numbers, as total mean predator numbers increased for all sized protected areas. 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, increasing total mean harvests.

The net social cost, in terms of forgone resource rent, is depicted in Figure 5 for both fisheries. For all dispersal levels, there is a slight diminishing cost of protected area establishment. From Figure 5, 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.

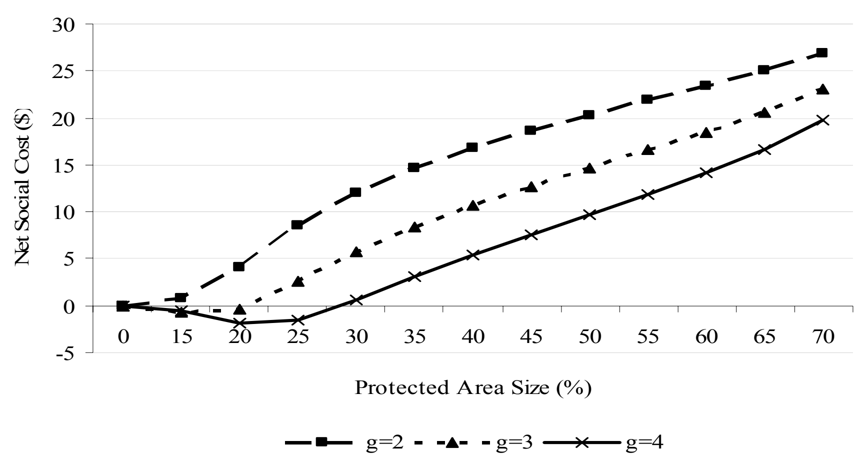


Figure 6: Net Social Cost of Establishing a Marine Protected Area with Density-Dependent Dispersal

Due to increased mean predator harvests in the surrounding fishing grounds, total mean effort levels in the predator fishery increased. For the prey species fishery, total mean effort levels decreased. Despite this, total mean effort levels (combined for the two fisheries) increased for all dispersal levels. It is possible that post protected area establishment total employment in the fishing industry may not decrease if fishers are able to shift their operations between fisheries.

The variation of mean resource rent decreased with increased size of protected area. This result was also seen in the variation of mean harvest levels. The hedge effect was lessened with increased dispersal, as with increased dispersal, the reliance of harvests on dispersal also increases. As dispersal is analogous to an excess supply (determined by within patch interactions), it is more variable than harvesting the underlying resource itself, making total harvests more variable. This was seen for predators but not for prey. Mean fishing ground harvest variation increased for prey and decreased for predators.

Sink-Source Dispersal

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

The net social cost in terms of forgone resource rent from protected area establishment is given in Figure 6. A minimum sized protected area was required to obtain a net benefit. Under high dispersal levels, g equal to 4, the establishment of a protected area of 25 percent of the fishery maximised the rent from the fishery. For lower dispersal rates, no protected area yielded an increase in resource rent. The lesser benefits from smaller protected areas under sink-source dispersal was because of the difference in the dispersal drivers.

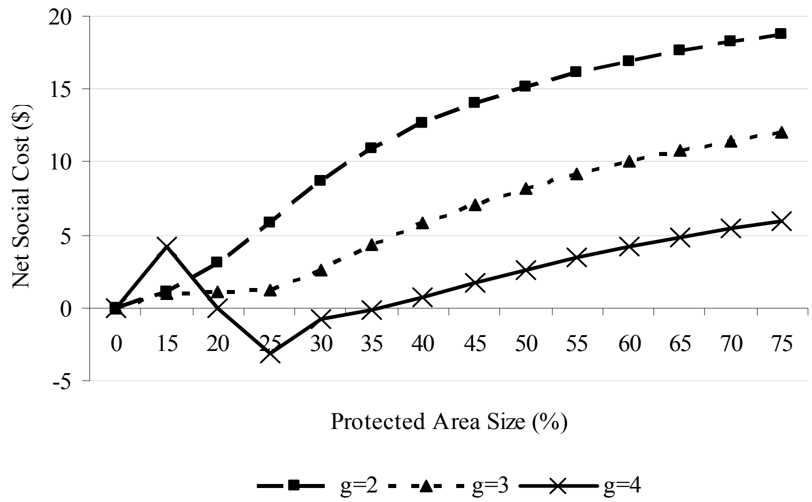


Figure 6: Net Social Cost of Establishing a Marine Protected Area with Sink-Source Dispersal

The difference between the population densities pre and post protected area creation is large, especially for predators, resulting in extra flow from the protected area under density-dependent dispersal. Under sink-source dispersal, differences in densities do not drive the level of dispersal, meaning the differences in patch population densities did not increase migration. Further, the level of dispersal from the protected area is more reliant on the carrying capacity of that patch. This reliance meant that a minimum sized protected area was required for the opportunity cost of protected area creation to be offset by dispersal.

Mean effort levels in the predator fishery increased post protected area establishment. However, for the prey fishery, total effort levels fell. Overall total mean effort levels increased. This result was seen for all sized protected areas with the exception of protected areas of 15 percent for low dispersal levels (*g* equal to 2).

Variation in the 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. For larger sized protected areas, variation in resource rents decreased, producing a hedge against normal fishery variation. Mean harvest variation for the fisheries increased in the open fishing grounds.

Scenario 2: Heterogenous Catch

With heterogenous growth, the area chosen to be protected was assumed to be of a higher biological character than the surrounding fishing ground. Growth rates in the protected area were assumed to be a factor of 1.25 greater than those estimated, with growth rates in the fishing grounds assumed to be adjusted by a factor of 0.75. The choice of these factors was arbitrary but was chosen to represent the differences in biological character.

Given low dispersal rates (*g* equal to 2), the creation of a protected area in the fishery always decreased the mean resource rent generated in the fishery. As the dispersal rates increased, small sized protected areas generated a net gain to the fishery. The main effect of protected area creation was seen for the predator species. Small sized protected areas increased mean predator numbers and decreased mean prey numbers, as without fishing pressures, the population ratio changed. The increased and subsequent movement of mean predator numbers drove the changes in the level of resource rent. Results for the surrounding fishing ground were similar to those under homogenous growth.

Changes in effort levels differed for each of the fisheries. Total effort levels in the fishery targeting predator species also increased. For the prey fishery, total effort levels fell. Despite this, for certain dispersal levels (*g* equal to 2 and 3), the increase in effort in the predator fishery exceeded the effort fall in the prey fishery.

Under this scenario the marginal opportunity cost curves shifted to the left. Under certain dispersal rates, smaller-sized protected areas were optimal. The marginal opportunity cost curves are shown in Figure 7. Again, as protected area size increased, the marginal opportunity cost is diminishing.

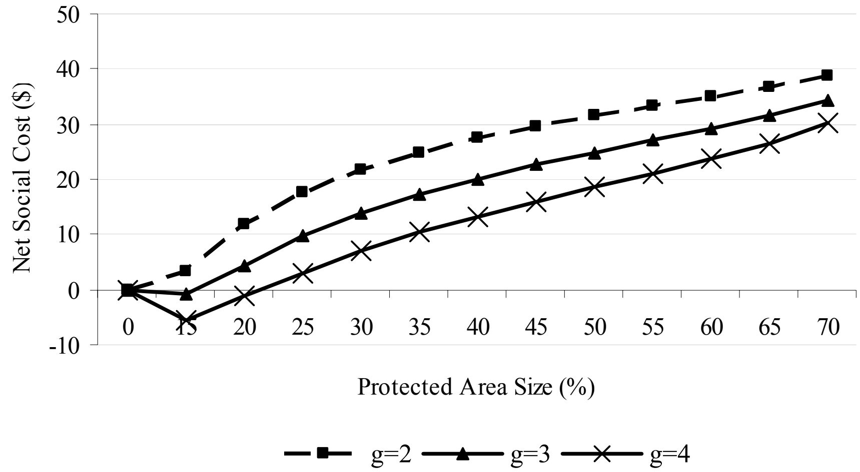


Figure 7: Net Social Cost of Establishing a Marine Protected Area with Density-Dependent Dispersal Scenario 2

The ability for protected areas to hedge against variation in populations and resource rent was lessened given that areas of higher biological character were selected for protection. For prey species, protected areas of only very small size (up to 15 percent of the fishery) decreased the variation in mean prey numbers. Also, larger protected areas increased the variation in predator numbers.

Sink-Source Dispersal

Protected area creation decreased total mean resource rent in the fishery for all sizes. The fall in resource rent given this scenario was due to the ability of the predator stocks to influence the outcome from protected area creation. Whilst prey harvest in the fishing ground fell as a result of increased predator numbers not matched by the increase in prey numbers, there were not enough predators to compensate for the lost catch. The remaining results were similar to the other scenarios with the exception of mean prey harvest levels in the surrounding fishing ground. As dispersal levels increased, larger protected areas were required to increase mean prey harvests due to increased predation.

The marginal opportunity cost curves for sink-source dispersal and heterogenous environments are shown in Figure 8. Effort levels in the fishery decreased for low dispersal levels (g equal to 2) for both predator and prey species for all protected area sizes. For higher dispersal levels, a predator fishery effort level increased, and was such that aggregate effort levels also increased.

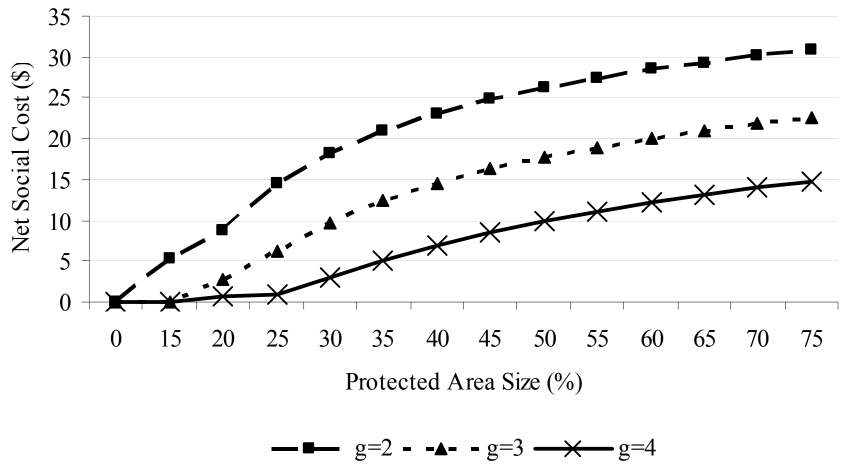


Figure 8: Net Social Cost of Establishing a Marine Protected Area with Sink-Source Dispersal Scenario 2

The ability of protected areas to reduce the variation in mean resource rent, and prey biomass was enhanced by protecting areas of greater biological character. Protected area creation of all sizes lessened the variation in mean resource rent levels. Further, small sized protected areas decreased variation in mean prey and predator numbers and prey harvests in the surrounding fishing grounds.

Scenario 3: Improved Institutional Arrangements

Optimal biomass levels for prey and predator species were determined using the optimal biomass relationship derived by Greenville and MacAulay (2005). The optimal biomass in each patch is found using:

$$\delta = \frac{c_i^j w_i^{j\prime}\left(F_i^j(\bullet) + z_i^j\right)}{w_i^j\left(p_i^j q_i^j w_i^j - c_i^j\right)} + \left(F_i^{\prime j}(\bullet) + z_i^{j\prime}\right). \qquad (9)$$

where w_i^j is the biomass of species j in patch i ($w_i^j = J_i^j + z_i^j$), $F_i^j(\bullet)$ is the growth function of species j in patch i, δ the social discount rate, $w_i^{j\prime}$, $z_i^{j\prime}$ and $F_i^{\prime j}(\bullet)$ are the first derivates of w_i^j, z_i^j and $F_i^j(\bullet)$ with respect to biomass J_i^j, with all other variable as defined.

When solving for optimal biomass levels, an interesting result was observed. Given the estimated parameters, it was optimal to prevent fishing on small sub-populations of prey stocks. A greater return can be obtained from the resulting increased catch and migration of both species. This occurs due the estimated parameter for the carrying capacity of predators given a level of prey biomass (*b*). The optimal biomass is depicted in Figure 9 against the parameter *b*. For value of *b* less than 0.18, it is optimal not to fish the prey biomass in the small patch (in this case the source patch). If a constraint is added to maintain fishing of this stock, optimal resource rent is lower than otherwise. For certain values of *b*, it is optimal to protect the prey stock, meaning that for a single species, a marine protected area is optimal in the absence of other factors (such as uncertainty) when consideration is given to that species' links with other harvestable species.

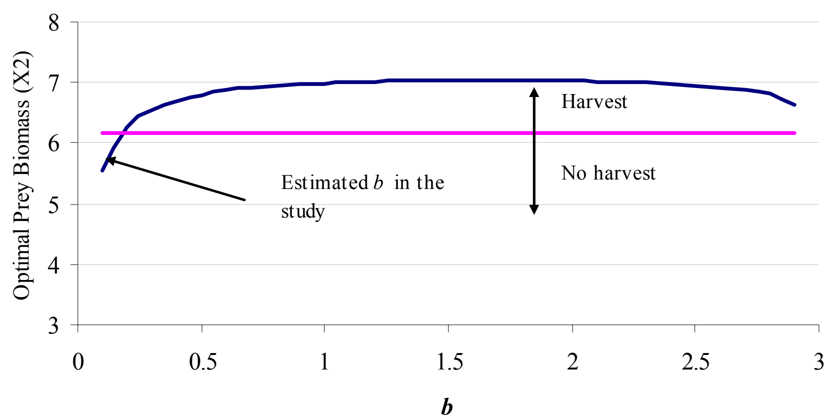


Figure 9: Predator Biomass Carrying Capacity Parameter vs Optimal Prey Stock (source patch size 20 percent of fishery)

Given optimal biomass levels and homogenous growth rates, no harvest on prey was optimal for patches of 15 to 20 percent of the fishery prior to protected area establishment. The results presented represent the protection of a single species. If harvest of both species existed prior to establishment in all patches, a protected area increased the resource rent in the fishery for sizes around 15 percent of the fishery. This occurred as the gain from the protection of the smaller prey biomass was greater than the lost revenues from the smaller predator biomass. However, this instance represents non-optimal extraction and as such the results are not presented here as they are similar to those in scenario 1.

The improvement in the management of the resource shifted the marginal opportunity cost curves up and to the left. Thus, no size of protected area was found to be optimal for *both* stocks. However, this does not imply that the use of a protected area is non-optimal. On the contrary, for optimal management to occur, protection of prey stocks in small patches of the fishery was required. From this result, multi-use zones where certain fishing activities are prohibited will be optimal. The marginal opportunity cost curves under optimal management and density-dependent dispersal are shown in Figure 10.

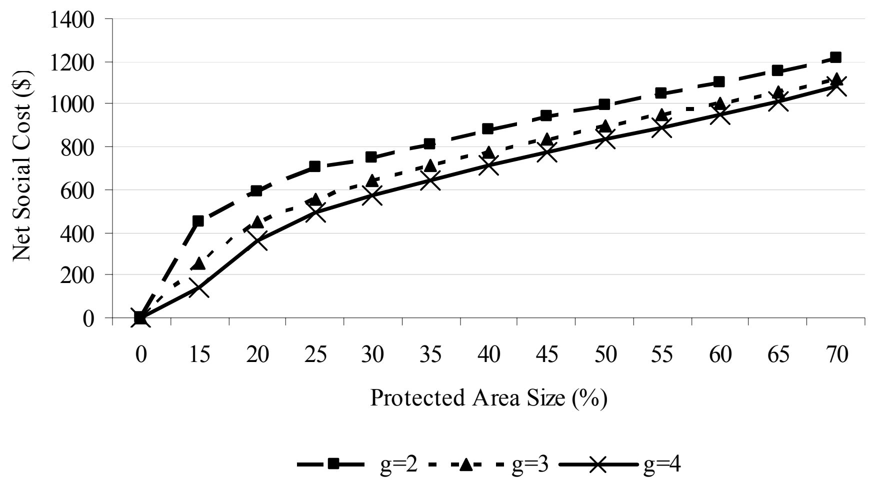


Figure 10: Net Social Cost of Establishing a Marine Protected Area with Density-Dependent Dispersal Scenario 3

The increase in mean effort applied to predator species was greater than the fall seen for prey species for both small and medium sized protected areas. For protected areas greater than 75 percent of the fishery, total mean effort fell. Despite a fall in resource rent and harvests, protected area establishment was likely to have a lesser effect on employment in the fishing industry. However, these new effort levels represent non-optimal exploitation.

In terms of variation, protected areas with small levels of dispersal increased the variation of mean resource rent and stocks. For larger dispersal levels, the outcome of protected area creation on mean resource rent and mean harvest variation were the same as seen for the non-optimal management of the resource.

Sink-Source Dispersal

For all sized protected areas, total mean resource rent decreased. Again, this result needs to be considered in the context of prey stocks being protected for small sized patches, thus the use of a multi-zone protected area. Mean prey numbers increased for small sized protected areas. Despite increases in mean predator harvests in the fishing ground, the increase was not great enough to lead to an overall increase in the mean effort in the predator fishery. For the prey fishery and overall, total mean effort levels fell. The marginal opportunity cost curves for protected area creation are given in Figure 12. Small sized protected areas had a lower opportunity cost than that seen for density-dependent dispersal.

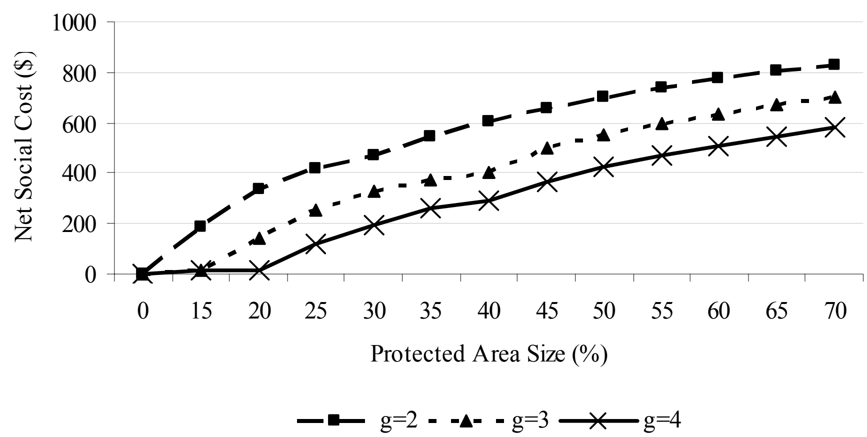


Figure 12: Net Social Cost of Establishing a Marine Protected Area with Sink-Source Dispersal Scenario 3

Results obtained for variation were similar to those under the other scenarios. However, for smaller sized protected areas, mean resource rent variation increased with medium and high dispersal levels (*g* equal to 2 and 3). Variation in total mean predator harvests also fell for most sized protected areas which were not seen under sub-optimal management. For high dispersal levels, all harvests and rents became more variable than under sub-optimal management due to the greater dependence of harvests on dispersal.

7. Discussion

Under the assumption of both homogenous and heterogenous growth rates it was found that protected areas could be used as a fisheries management tool in the Manning Bioregion. Outcomes from protected area creation were dependent on some level of management of the fishery. Without some form of management, no structure exists to capture the benefits from improved resource use, and therefore, protected areas should be viewed as a complement to current management arrangements and not a replacement. For reserves to be successful in fisheries management, they need to be integrated with current arrangements and monitored to ensure continued success (Grafton *et al.* 2005b).

Both the nature and extent of the dispersal from the protected area are key features in determining the economic outcome from creation. The greater the level of dispersal, the greater the benefits 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, the value of small sized protected areas is enhanced through density-dependent dispersal. Under sink-source dispersal, 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.

If areas of higher quality are protected (heterogenous patches), the potential for protected areas to improve resource rents are more limited. Despite this, for medium to high dispersal patterns, small sized protected areas can improve resource rents under density-dependent dispersal. In conjunction with this, these protected areas have the potential to lower variability in harvests and rents.

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 benefits of protected area creation are limited by the effects of predation. The protected area is less likely to increase mean harvests and fishery rent post establishment. Further, certain sized protected areas increased the variability of mean harvests, meaning that overall harvests were not only reduced but more variable. The counter situation occurred for the predator fishery, which is more likely to benefit from protected area creation. Increased mean predator numbers increased mean predator harvests. Despite the potential gain, in the open fishing grounds harvests of predator species is likely to become more variable.

The distributional effects were seen through changes in pre and post effort levels. Under most scenarios and dispersal patterns, total effort in the fishery increased. This was due to the increase in effort applied to predator species. The distributional effects are likely to lead to opposition from certain fishers despite the potential Pareto improvement. Grafton and Kompas (2005) suggest a way to manage these concerns is to establish protected areas of smaller than optimal size in different locations to both simultaneously improve ecology and economic outcomes. Compensation schemes can be used for lost access rights, and can be viewed as a re-distribution of the potential benefits. In setting up such compensation schemes, managers should be mindful of the overall costs and benefits, including the monitoring and enforcement costs of protected area establishment.

The greater effort levels in the surrounding fishery may offset the conservation outcome achieved by the protected area. If further environmental damage is created through this shift, then those costs would need to be considered against the benefits that would accrue to the fishery. However, the shift represents a movement in fishing practice away from trawling methods (often deemed destructive) to less destructive trap and line methods.

Another potential method to overcome opposition to protected area creation is to ensure the overall fishing industry is flexible enough such that it is possible for effort to shift from one fishery to the other, limiting any fall in employment (only if sustainable). This result would limit the potential political pressure that is generated through the establishment of a protected area. Despite this, given optimal management of the resource, total harvests would fall despite potential increases in effort (a shift away from the optimal steady-state position) meaning that the returns to individual operators would potentially fall.

For the two fisheries as a whole, the creation of 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, limiting the ability for biomass in the protected area to reduce normal fluctuations in populations caused through environmental stochasticity.

For small patches, given the parameter estimates, it was found that it was optimal to protect prey biomass. The return from harvesting the extra predator biomass generated from the patch was greater than return from harvesting the underlying prey stock. It is better to 'value add' the prey stock by allowing them to be consumed by the predator stocks. Key determinants of this result are the predator stock carrying capacity parameter (b) which determines, in part, the growth rate of predators (given logistic growth), and the carrying capacity of the prey stock (K_i).

An implication to be derived from this result is the potential to use multi-use protected area zones. Given certain characteristics of the stock and the fishery, multi-use zones that prohibit the taking of a certain species can be used as a tool to achieve the optimal management of fishery resources. Multi-use zones have become a common element in many marine protected areas, and are advantageous on both political grounds (through reduced opposition), and on economic grounds (as they can be used to maximise the value of the resource).

8. Concluding Comments

Protected areas have the potential to become a useful tool for the management of fisheries. 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 separately, so the full effect on all the fisheries that operate in that region is unknown. Effort in each of these fisheries is affected differently, and as a protected area may adversely affect one group compared to another if fishers are able to shift operations between fisheries.

Results from the model mean that benefits in the form of improved resource rent and reduced harvest variation are possible. These results are, however, 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 behaviour 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 maximising the resource rent generated in the fishery.

Under optimal steady-state management of fishery resources, the protection of both species is non-optimal, with the protection of prey species in small patches is optimal. The use of multi-use zones within a protected area which allow for the protection of prey species but allow the taking of predator species would improve the level of resource rent generated in the fishery.

The analysis conducted in the paper has focused on the use of marine protected areas as a tool for fisheries management. Consideration has not been given to the non-use benefits of protected areas. Despite this, a framework exists to link the non-use 'demand' for protected areas against the marginal opportunity cost or 'supply' of protected areas. If the demand for protected areas as a function of size could be estimated, the socially optimal level of protected area could be found by finding the intersection between the 'supply' and 'demand' curves.

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