Beattie, A., V. Christensen, U.R. Sumaila and D. Pauly. 2001. Marine protected areas in the North Sea: a preliminary bioeconomic evaluation using Ecoseed, a new game theory tool for use with the ecosystem simulation Ecopath with Ecosim p. 32-42 In: U.R. Sumaila, J. Alder and G. Weingartner (eds.) Economics of Marine Protected Areas. Fisheries Centre Research Reports 9(8).

MARINE PROTECTED AREAS IN THE NORTH SEA: A PRELIMINARY BIOECONOMIC EVALUATION USING ECOSEED, A NEW GAME THEORY TOOL FOR USE WITH THE ECOSYSTEM SIMULATION ECOPATH WITH ECOSIM

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Abstract

The use of marine protected areas (MPAs) as a basic management tool to limit exploitation rates in marine fisheries has been widely suggested. Models are important in predicting the consequences of management decisions and the design of monitoring programs in terms of policy goals, however few tools are available that consider both multiple fleets and ecosystem scale dynamics. We use a new applied game theory tool, Ecoseed, that operates within a temporally and spatially explicit biomass dynamics model, Ecopath with Ecosim, to evaluate the use of marine protected areas in the North Sea in ecological and economic terms. Ecoseed builds MPAs based on the change in values of predicted rents of fisheries and the existence value of biomass pools in the ecosystem. We consider the market value of four fisheries: a trawl fishery; a gill net fishery; a seine fishery; and an industrial (reduction) fishery. We apply existence values, scaled such that their aggregate is similar to the total fishery value, to six biomass pools of concern: juvenile cod, haddock, whiting, saithe, seals, and the collective pool ‘Other predators’ that includes marine mammals. Four policy options were considered: to maximize the rent only; to maximize the existence values only; to maximize the sum of the rent and existence values; and finally to maximize the sum of the rent and the existence values, but excluding only the trawl fleet from the MPA. Ecoseed suggests that policy goals that do not include ecological considerations can negatively impact the rents obtained by the different fishing sectors. The existence values will also be negatively impacted unless the MPA is very large. Ecoseed also suggests that policy goals based solely on existence values will negatively impact most fisheries. Under policy options that included ecological considerations, maximum benefits were derived from an MPA that covered 25-40% of the North Sea, placed along the southern and eastern coasts. Finally, Ecoseed suggests that an exclusion of the trawl fishery only from the MPA can provide small to substantial positive impacts to most species and fleets.

1. Introduction.

The global situation of fisheries presently is bleak. Worldwide, collapsed or severely depleted fisheries are common, including in the North Sea (FAO 1997, Garcia and Newton 1997, Sissenwine and Rosenberg 1993). Often, this can be attributed to failed management policies, (e.g., the Canadian east coast cod fishery or the Peruvian anchoveta fishery). Traditional fisheries management is based on output controls, for example setting an annual total allowable catch (TAC) equal to the estimated biomass times some desired exploitation rate. The estimated biomass, however, is subject to large uncertainty as are policies based upon them (Walters 2000, Botsford *et al.* 1997). This inherent uncertainty leads to the pathology of the ‘ratchet effect’ (Ludwig *et al.* 1993): continually increasing catches because detrimental effects are uncertain. With the ratchet effect established, stock collapse may occur (Botsford *et al.* 1997).

A shift in management towards input controls, or directly limiting exploitation rate, is increasingly seen as necessary to the process of rebuilding or sustaining fisheries (Walters 2000). Directly limiting exploitation rates can be accomplished through various methods, such as the establishment of marine protected areas (MPAs) that physically limit the percentage of the population vulnerable to exploitation (Bohnsack 1990, Walters 2000). Increasingly, MPAs are being proposed as a primary management tool (Clark 1996, Walters 2000). With some portion of the ecosystem remaining intact, adaptive management experiments may also be conducted that can further reduce uncertainty (Botsford *et al.* 1997).

Though MPAs in various forms already exist (Farrow 1996, Sumaila *et al.* 2000), two concerns have so far prevented their widespread use. The first of these concerns is ecological. At present, the impacts of MPAs are not well understood (Holland 2000), in part because they were implemented without careful consideration, inherently reducing the likelihood of attaining any conservation objectives (Allison *et al.* 1998). The second concern is of an economic nature. Specifically, it is feared that MPAs would reduce yields substantially (Hastings and Botsford 1999). In order to address these concerns, modelling becomes an important first step in the design and implementation of MPAs.

An evaluation of MPAs will require new and more comprehensive models than those presently used in fisheries management to be useful in the real world (Walters 2000). Several models have already been proposed to evaluate and predict the impacts of MPAs, (e.g., Sumaila 1998, Holland 2000, Mangel 2000, Walters 2000). We have built on the work of Walters *et al.* (1999) and Walters (2000) to combine applied game theory, a useful tool in the economic analysis of fisheries (Sumaila 1999), with a multi-species, multi-fishery, temporally and spatially dynamic ecological model, Ecopath with Ecosim (EwE). This tool, Ecoseed, was developed as a 'snap-on' module that operates within the spatial simulation component (Ecospace) of the software.

The North Sea has a history of fishing dating back centuries, and presents a good test case for evaluating the impact of MPAs. Most stocks today in the North Sea are considered either fully exploited, for example, the haddock and sole fisheries, or overexploited, most notably the herring and cod stocks. This has resulted in a call to implement or study a number of possible conservation measures, including reductions in fleet sizes and area closures. The Sea Around Us Project (for more information see http://www.fisheries.ubc.ca) recently updated an EwE model of the North Sea ecosystem, tuned with Multispecies Virtual Population Analysis (MSVPA) data. Using this model, we conducted a preliminary evaluation of the size and placement of potential MPAs in the North Sea. Specifically, we evaluate the impact to the rents obtained by four fisheries and the existence value of six groups. We consider four differing management policies: to maximize the rent only; to maximize the existence values only; to maximize the combined rent and existence values; and finally, to maximize the rent and the existence values, but excluding only the trawl fleet from the MPA.

2. Methods

2.1 Ecopath with Ecosim

The foundation of the EwE suite is an Ecopath model (Christensen and Pauly 1992, Pauly *et al.* 2000), which creates a static mass-balanced snapshot of the state of an ecosystem represented by trophically linked biomass 'pools'. The biomass pools consist of species, or species groups. Ecopath data requirements are relatively simple, and generally already available in the literature: biomass estimates, total mortality estimates, consumption estimates, diet composition, and fishery landings and values from the ecosystem. Ecosim puts the Ecopath model in a temporally dynamic setting, using a system of differential equations that express changes in the biomass of pools as a function of time varying biomass and harvest rates (Walters *et al.* 1997). Ecosim has been applied in the study of the role of top predators in ecosystems and the impacts of fishing (reviewed in Pauly *et al.* 2000), but until the addition of Ecospace, it lacked any explicit spatial component system (for more information on Ecopath with Ecosim, see http://www.ecopath.org).

Ecospace allows the evaluation of spatially explicit policies, such as the implementation of MPAs on both large and relatively small scales. Ecospace is essentially a grid or two dimensional matrix of 'cells', each cell consisting of a single Ecosim model (initially identical as Ecosim inherits its parameters from Ecopath). This matrix of cells is then expressed at the user interface level as a map. Each cell in the map, excluding land cells, is linked through two processes: dispersal of organisms, and the redistribution of effort due to changing profitabilities and/or the creation of areas closed to fishing (Walters *et al.* 1999, Walters 2000).

The user defines the base map by sketching it on the interface with the computer mouse. Over the top of the base map can be sketched: patterns of relative fishing cost (effort 'avoids' high cost cells, for example, cells far from their home port that require high fuel costs to reach); patterns of relative primary production; and patterns of habitat to which biomass pools and fishing fleets can be assigned (Walters *et al.* 1999, Walters 2000). Recent modifications of Ecospace allow the estimation and comparison of the 'value' obtained from MPAs, either as a function of the monetary value of fisheries or the change in biomass of pools. It was recognized that the information included in these routines could be adapted to evaluate the size and placement of MPAs, and this led to the development of Ecoseed.

2.2 Ecoseed.

In game theory, one is concerned with the actions of decision makers who have an awareness both of the other decision maker's actions, and the impact of their own actions upon the others (Rasmusen 1995, Sumaila 1999). A fully described game would include players, strategies and payoffs; all together, these comprise the rules of the game. Games can be cooperative (players work together to maximize joint benefits), noncooperative (players seek to maximize only their own benefits), with or without conflict (Rasmusen 1995).

Ecoseed is a multi-player, cooperative or non-cooperative model. In Ecoseed, the players are the fishery managers or other interested parties (the regulator), and the fishing fleets (the fleet[s]). The fleet's strategy is to work within the constraints set forth by the regulator to maximize its rent through redistribution of effort. The regulator can explore several strategies (policy objectives): either to maximize the fleet rent, or to maximize the benefit to a species or group of species (or increased habitat leading to an increased species biomass may be a surrogate). The final strategy available to the regulator is to find a compromise that maximizes the benefits to both the fleets and the biomass pools through some form of tradeoffs. The regulator initiates the game by choosing a strategy, Ecoseed selects an area to place an MPA, the fleets respond by redistributing their effort, Ecoseed responds by either increasing the size or changing the placement of the MPA, and the outcomes are calculated. The game is concluded when all fishable area is closed.

The primary goal of an Ecoseed game is to allow the regulator to evaluate as many differing scenarios as possible. The outcomes resulting from different strategies collected and tested during gaming can then be used for informed policy analysis and implementation. It should be stressed that, as for any model, Ecoseed does not provide the 'right' numbers. It can shed light on the expected direction and magnitude of change resulting from strategies undertaken, given the set of input parameters. As such, Ecoseed should also assist in the design of monitoring programs that must be a necessary part of the establishment of MPAs.

The selection of the 'best' cell from a single or set of seed cells is guided by the primary Ecoseed objective function, which expressed simply is:

> Best cell =Max (Sum of surplus production from fisheries + Sum of existence value of species)

(1)

Where the value of surplus production and existence values are summed over all water cells, all fleets and all species for each seed cell considered. Equation (1) can be formalised as follows:

$$O_{i,j} = \sum_{n=1}^{i,j,k} (R_{i,j,k} - FC_k - EC_{i,j,k} - SC_{i,j,k}) + \sum_{n=1}^{i,j,s} (B_{i,j,s} * V_s) \qquad (2)$$

where (i) is the number of rows in the grid map, (j) is the number of columns, R is the total revenue in cell (i,j) for fleet (k), FC is the fixed cost for fleet (k), EC is the cost associated with effort expended in cell (i,j) by fleet (k). Note here that since effort is presently constant in the simulations, the value of EC is fixed. SC is the spatial cost of fishing in cell (i,j) for fleet (k), B is the biomass in cell (i,j) of species (s) and V is the existence value per unit of species (s). R is calculated as follows:

$$R_{i,j,k} = \sum_{n=1}^{s,k} (Y_{i,j,s,k} * P_{s,k}) \qquad (3)$$

where Y is the catch of species (s) in cell (i,j) for fleet (k) and P is the ex-vessel price of species (s) for fleet (k). Note that the Y for any cell is a function of B for that cell. For a detailed description on the estimation of biomass, catch and effort for cells in Ecospace, see Walters *et al.* (1999).

The objective function O is then maximized when the sum of the rent from fisheries and the existence values is maximized, given the relevant constraints. Further, setting the rent to zero causes O to be a function of existence value only, and conversely. Finally, note that sum of EC over all cells is constant in the model as long as total effort remains constant. Thus, the fleets mimic the constraint of irreversible capital investment, similar to the assumption of Sumaila (1995, see also Clarke *et al.* 1979): the disinvestments of capital (boats) cannot be achieved without substantial economic loss. The ability to include variable effort as a policy option or fleet response is in development.

2.3 The North Sea model.

2.3.1 Ecopath setup.

An Ecopath model of the North Sea was constructed as an updated version of the model presented by Christensen (1995). The model was updated to include data on biomasses, production and consumption from the key-run of the most recent version of the ICES MSVPA (Vinter, pers. comm., DIFRES). The base period represented is changed to the year 1970, in order to take advantage of information from time series data. Further, catches have been added for the groups not included in the MSVPA, based on the STATLANT database as available from ICES (www.ices.dk). The model consists of 31 biomass pools, from detritus and primary production to top predator fish and seabirds (see www.Ecopath.org for details of the model parameterization).

Four fisheries are included in the model: a trawl fleet; a gill net fleet; a seine fleet; and an industrial (reduction) fishery. These fleets were chosen to represent the majority of fishing activity in the North Sea. The catch allocation between fleets is assumed. Discarding is not explicit, however no commercial value is applied to the trawl fleet's catches of juvenile biomass pools.

Table 1 shows the values by species and fleet used in estimating the rents, and the existence values. The ex-vessel prices were obtained from http://www.fis.com/fis/marketprices/ and were current as of July 2000. The existence values of the six groups were comparable and set such as to sum to a value similar to that of the value of the fisheries at the start of the Ecoseed run.

Table 1. Values applied to the individual fisheries by biomass pools of interest, and total values, costs and profits by fishery estimated by Ecopath.

	Fishery value (\$·kg^{-1})					Existence value	Total value
Group	Trawlers	Gill net	Seiners	Industrial	Total	(\$·kg^{-1})	(\$·kg^{-1})
Cod	0.59	0.25			0.85		0.85
Haddock	0.46	0.20			0.65		0.65
Herring	0.30		0.12		0.14		0.14
Mackerel	0.12		0.47		0.59		0.59
Norway pout				0.19	0.19		0.19
Plaice	0.22	0.10			0.32		0.32
Saithe	1.47				1.47		1.47
Sandeel				0.90	0.90		0.90
Sole	0.13	0.60			0.19		0.19
Whiting	0.13	0.60			0.19		0.19
Gurnards	0.19				0.19		0.19
Horsemackerel				0.10	0.10		0.10
Other predators						0.27	0.27
Seals						< 0.01	< 0.01
West mackerel	0.20		0.10		0.12		0.12
Juvenile cod						0.50	0.50
Juvenile haddock						1.25	1.25
Juvenile saithe						0.30	0.30
Juvenile whiting						0.77	0.77
Sprat				0.90	0.90		0.90
Dab	0.20				0.20		0.20
Total value	3.39	0.66	0.69	0.38	5.12	2.38	7.50
Total cost	2.88	0.53	0.55	0.32	4.29		
Total profit	0.51	0.13	0.14	0.60	0.84		

2.3.2 Ecosim, Ecospace and Ecoseed setup.

For simulation purposes, Ecosim was set to run for 50 years. The first 21 years were fit to time series data. All Ecoseed runs were set to begin the year following the end of the time series data.

Five habitats types were defined according to bathymetric contours. Table 2 shows the habitat types, habitats assigned to biomass pools, and dispersal rates of the biomass pools. Biomass pools were assigned to habitats based on described distributions within the system, if known. If descriptions were not available, the group was assigned to all habitats. Their distribution developed only as a result of trophic interactions and tradeoffs between the need for food and predation risk. Penalties for dispersal into non-optimal habitats were left at the default values (5 times movement rate, 2 times the vulnerability for predation, and 1% of feeding success) for all groups except the juvenile cod. For this group the penalties were reduced (10 times the movement rate, same vulnerability, 90% feeding success) in order to prevent the cod groups from going extinct in the simulation.

Table 2. Individual group assignments to habitat types, base dispersal rates and penalties for not being within a preferred habitat type. A '+' sign indicates that the habitat is preferred by the biomass pool.

	Depth (m)						
Group	0-30	30-50	50-200	200-400	>400	All depths	Base dispersal rate (km·year^{-1})
Cod		+	+				150
Haddock	+	+	+				10
Herring						+	100
Mackerel						+	10
Norway pout			+	+	+		100
Plaice	+	+	+				10
Saithe			+	+	+		10
Sandeel	+	+	+				10
Sole	+	+					10
Whiting		+	+				100
Birds						+	300
Gurnards	+	+	+				10
Horsemackerel		+	+				10
Other predators						+	10
Raja	+	+	+	+			10
Seals	+	+					300
West mackerel				+	+		100
Other invertebrates						+	5
Juvenile cod	+	+					10
Juvenile haddock	+	+	+				10
Juvenile saithe			+	+			10
Juvenile whiting	+	+					10
Sprat	+	+					10
Dab	+	+	+				10
Copepods						+	300
Euphausiids		+	+	+	+		300
Other crustaceans						+	10
Echinoderms						+	10
Polychaetes						+	10
Other macrobenthos						+	10
Phytoplankton						+	300
Detritus						+	5
Proportion total area	0.26	0.15	0.29	0.20	0.10	1.00	

Figure 1A shows the base map of the North Sea used in the Ecoseed runs. Note that each cell is 5 km in length. Shown on the base map here is the habitat types, or depth zones. The spatial cost of fishing was set so that cells greater than 3 from the coastlines were considered to be 20% more costly to fish, as a result of increased fuel costs. We also assume that fuel costs represent the greatest factor in the spatial component of the cost of fishing.

3. Results and Discussion

Maximum and minimum values of the predicted rent, existence value and objective function are summarized in Table 3, including the percent change relative to the value just prior to the addition of MPA cells, for all policy scenarios. Results obtained under each policy are described individually below.

3.1 Policy A: Maximizing the rent only.

This policy resulted in the only predicted decline in existence value, and rent under this policy declined to less than zero with the least total MPA coverage (Table 3). Figure 2A shows the predicted impacts as a function of increasing MPA size. The predicted rent never increased under this policy, but declined less than 5% until 40% MPA coverage. No positive benefit to the existence value is predicted until greater than 70% of the area was MPA. Figure 1B shows the proposed MPA for 40% (dark grey cells) coverage and 70% (dark + light grey cells) coverage. The fishery does not lose more than 5% of its initial rent until areas to the south and east are selected. The initial cells selected are along the Eastern coast of the British Isles, and tend to be mostly land.

Table 3. Minimum and maximum values of the rent, existence value and objective function and the percent MPA coverage at which they were observed under the four different policy scenarios. The percent change from the initial value is shown in brackets.

Policy		Maximum value ($\$\cdot km^{-2}$)	MPA coverage (%)	Minimum value ($\$\cdot km^{-2}$)	MPA coverage (%)
A	Rent[a]	4.78 (+1)	2	1.52 (-68)	91
	Existence value	7.10 (+26)	100	4.27 (-24)	45
	Objective function	1.01	2	0.32	91
B	Rent[a]	4.74 (-)	0	0.30 (-93)	87
	Existence value	8.47 (+50)	37	5.62 (-)	0
	Objective function	1.51	37	1.00	0
C	Rent	4.74 (-)	0	0.00 (-100)	100
	Existence value	5.91 (+42)	28	4.16 (-)	0
	Objective function	1.08	23	0.60	100
D	Rent	4.74 (-)	0	0.41 (-91)	96
	Rent (trawl excluded)	2.04 (+20)	46	1.69 (-)	0
	Existence value	5.70 (+37)	41	4.16 (-)	0
	Objective function	1.08	37	0.59	96

[a] Point of last positive value

Our simulation suggests that placing an MPA based on a policy goal of minimizing the impact to commercial fisheries, ignoring ecological considerations, can have a strong negative impact on both the fisheries and the ecosystem. The explanation for this is straightforward. Cells were placed first in areas where there was relatively little effort being expended, either because the expected yields were low or because the cost to fish there was high relative to the expected yields. Cell blocks were also selected such that a minimal area was closed off initially. The first ten blocks added accounted for only 28% of the total area, with 39% being land cells. Further, the rent obtained by the trawl fleet accounted for more than half of the rent from all fisheries. In effect then, the selection of cells was primarily driven by the impact to the trawl rent. The effort from all the other fisheries was displaced then into open areas where the trawl fleet 'preferred' to fish. This can have two consequences, not mutually exclusive.

First, all fleet effort is redistributed and concentrated onto same grounds preferred by juveniles of several of the commercially fished species, importantly cod, haddock and saithe. The juveniles, bycatch species in the trawl fishery, were subjected to increased fishing mortality, and the existence value declined as a result. Second, the areas closed represented much of the available relatively low-cost areas open to the gill net and the seine fleets. This negatively impacted their rents. Similar negative impacts of the redistribution of effort due to closing grounds has been pointed out for other fisheries that target multiple species and stocks (Walters and Bónfil 1999). Here we add that in a multi-fleet setting, the economic impacts to different fleets need consideration. Overall, this management policy can lead to results that are neither biologically or economically justifiable.

3.2 Policy B: Maximizing existence value only, and Policy C: Maximizing combined rent to all fisheries and existence values.

Policy B resulted in the largest predicted increase in existence value (Table 3). The impact to the rent and the existence value here are both more dramatic (Figure 2B). The predicted rent declined linearly with increasing MPA size. The small increase in rent observed in the very last cell is a result of a zero value returned when no fishing can take place, thus the rent 'increases' from a negative number to zero. Note here that the seine fleet benefited from an MPA, with a maximum increase of more than 5% at between 20 and 25% MPA coverage. Figure 1C shows the proposed MPA for this game to 50% coverage. Cells selected here are mainly in the south-east section of the North Sea. Cells selected in this area under Policy A precipitated the greatest declines in rent. The predicted rent and existence values for Policy C were similar (Table 3). Here, the predicted rent declined at a slower rate, and was not less than zero (Figure 2C). As for Policy B, the seine fleet showed a predicted increase in rent, with a maximum increase of more than 5% at 36% coverage. Also similar to Policy B, the predicted existence value peaked, though at a lower value and at less total MPA coverage. Figure 1D shows the cells proposed as an MPA as a result of this game. The cells selected in this game are very similar to those for the previous game.

The results from management policies B and C differed dramatically from results obtained under policy A, but were similar to each other. In both cases, cells added to the MPAs first were cells to the south and east of the North Sea, primarily habitat for juveniles of major commercial species such as cod and saithe. The existence values were predicted to increase in both cases, and in both cases the increases began with the addition of only one block of cells. Further, Ecoseed predicts maximum benefits to the existence value would be obtained at between 25-40% MPA coverage of MPA. In ecological terms, Ecoseed predicts that the addition of MPAs that protect the juveniles of commercially important species are justifiable. At this level of coverage, however, only the seine fleet is predicted to have positive gains in rent, as much as 5%, while the trawl and gill net fleets have predicted losses greater than 10%. Holland (2000) found that the impacts of MPAs on yield to fisheries varied with species. Here, the seine fleet benefits, in part because it targets primarily herring and mackerel that are not targeted heavily by other fleets. The seine fleet does not have to cope with the increased effort by other fleets in a smaller area, and thus receives all the benefits in terms of yield of these species that the MPA has created. If all fisheries are considered equally important, however, then in neither scenario is an MPA economically justified.

3.3 Policy D: Maximizing the rent and existence values, excluding only trawl from the MPA.

This policy resulted in positive predicted values to both the rent (for fleets other than trawl) and the existence values (Table 3). The overall rent declined at slower rate than in the previous game, and at 100% coverage showed a loss of only 58% (Figure 2D). The losses here were primarily that of the trawl fishery, however, seine and industrial fleet experienced losses as well at high MPA coverage (Figure 2E). Similar to the previous two policies, the predicted existence value peaked, and at a similar percent total MPA coverage (Figure 2D). Figure 1E shows the cells selected for this game that provided the largest increase in existence value. While more cells were needed for a slightly smaller gain than for the previous two policies, otherwise excluding only the trawl fleet from the MPA resulted in the identical cells being selected.

This management option was explored as it became apparent that the trawl fleet had the greatest influence on the outcome of the simulations. This is primarily because the fleets predicted rent was more than all other fleets combined. In this scenario, the existence value showed a predicted maximum at just over 40% coverage, similar to the latter two policy options. The results concur with the findings of Sumaila (1998), who found that in the face of a shock to the system, large reserves could be bioeconomically beneficial if transfer rates of commercial species were high. Here the shock to the system is the removal of the trawl fishery. Dispersal rates for species here were set to 2-30 times the cells size, and MPAs were added in blocks of a maximum 16 times the cells size. Walters (2000) found that movement rates of 1-2 cells per year had considerable impacts, thus our dispersal rates here can be considered high.

The most striking difference from the previous policies observed here was the large scale increases in rent predicted for the gill net fleet. The predicted seine fleet rent increased as well, similar to the percent increase predicted under policy scenarios A and B, while the industrial fleet showed a predicted loss of less than 3% at the optimal coverage in relation to the existence value. With direct spatial competition for fish with the trawl fleet removed, we would predict small to substantial benefits would accrue to other fleets operating in the North Sea, and increased existence values. Thus, if a policy option is to control the exploitation rate of the trawl fishery, marine protected areas are both biologically and economically justifiable.

4. Conclusions

We have explored several different policy options in terms of size and placement of MPAs in the North Sea, using a game theory tool in combination with an ecosystem model recently constructed and tuned with MSVPA data. The size and placement of the MPA was determined according to its impacts to the rent obtained by the fleets, the existence value of species, or by a combination of the both. Several key points revealed through this exercise are as follows. First, careful evaluation of the possible consequences of policy decisions should be made before they are implemented. Assumptions that MPAs will provide benefits to the ecosystem or species of concern no matter where they are placed may not be valid, and in fact may cause more harm than good to the fishery sectors, and the ecosystem unless they are very large. Conversely, implementing an MPA based solely on ecological concerns would negatively impact all fisheries operating in the North Sea. Second, for policy options that considered either just the ecological or the ecological and economic impacts combined, the maximum size of an MPA necessary to benefit species of concern in the ecosystem is 25-40% of the total North Sea area. Ecoseed further predicts that the MPA should be along the southern and eastern coasts of the North Sea. Third, in policy options that consider all fleets equally, it was predicted that most fleets would be negatively impacted by the implementation of an MPA of any size in any area, but some would be positively impacted. Finally, if the exclusion of the trawl fleet only from the MPA were a policy option, Ecoseed predicts small to large positive impacts to both the economic rents for other fleets and the existence value of species.

Acknowledgements

The first author would like to thank the David Suzuki Foundation for a grant supporting the development of the model, and Carl Walters for discussions on Ecospace. RS, VC and DP acknowledge support from the Pew Charitable Trust through the Sea Around Us Project. DP also acknowledges support from a Canadian NSERC grant.

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Questions

Darwin Hall: Is rent calculated by maximizing the difference between price and cost, or is it the elasticity in prices between fish?

Alasdair Beattie: It does not include the consumer surplus; it only incorporates the producer surplus.

Rögnvaldur Hanneson: You say Ecopath is not data-hungry, but how can you tell who eats what?

Alasdair Beattie: You must evaluate the data that you use. Relative to other studies, Ecopath is much less data-hungry. In gathering diet composition data, the best thing to do is to use previous studies. There is no need to do it yourself. Fisheries biologists have done it in the past, and they continue to collect diet composition data because it can be collected fairly easily and inexpensively - such data exists for integrating into models.

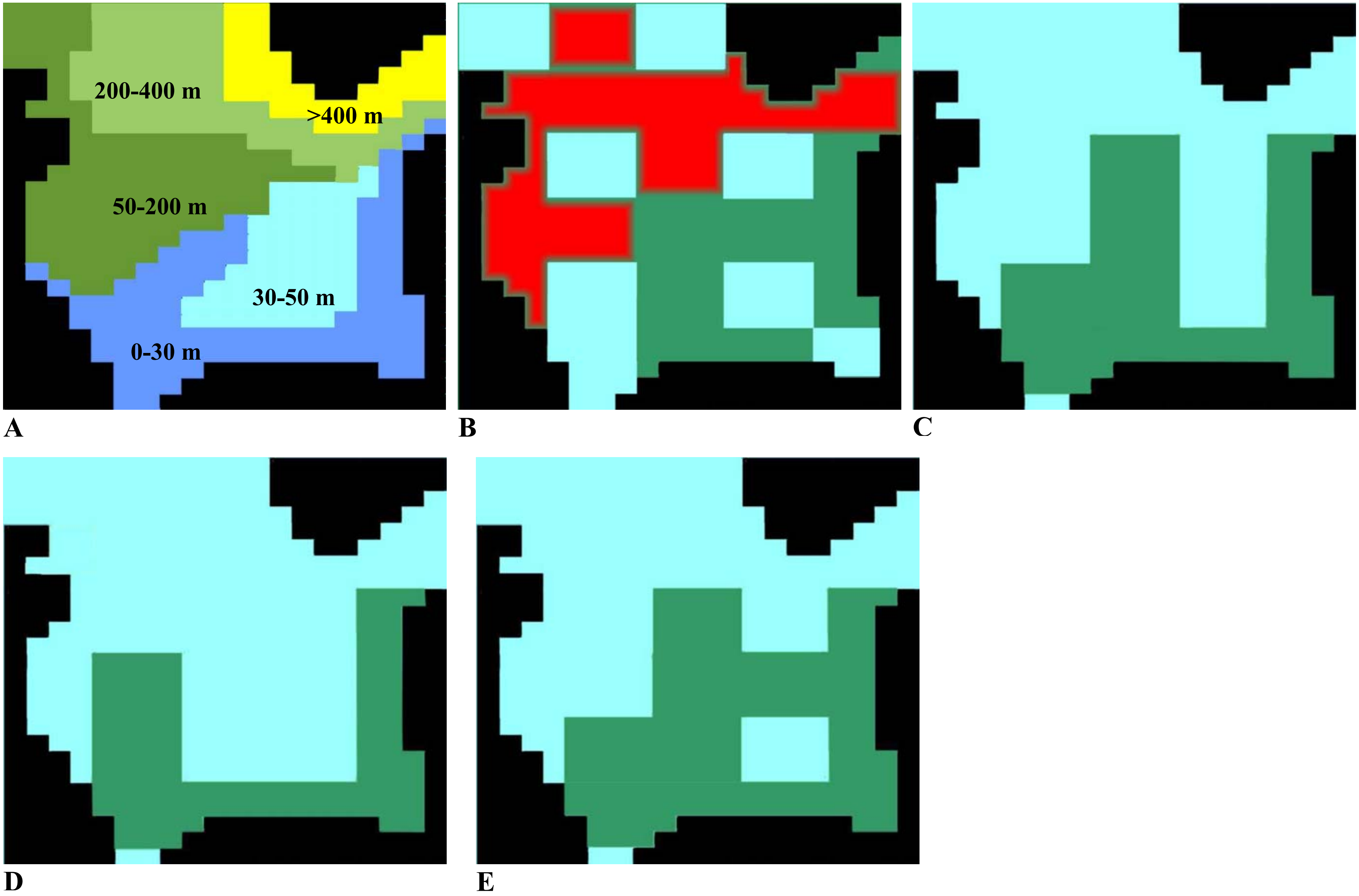

Figure 1. A. Basemap used for all Ecospace and Ecoseed simulations, showing the different habitat types. **B-E**. MPA size and placement predicted by Ecoseed under differing policy scenarios. The light and dark grey cells are MPA cells, the white cells are areas open to fishing. **B.** Maximizing the rent from all fisheries only. Dark grey cells indicate 40% coverage. The predicted rent declined by less than 5% until this point. An increase in the existence value is not predicted until greater than 70% coverage. **C.** Maximizing for existence value only. The predicted existence value increased by 50% at 36% coverage, shown here. Note that the cells selected are almost all different from those shown in dark grey in B. **D.** Maximizing for the combined rent and existence values. The maximum predicted increase in existence value in this game, 42%, at a coverage of 27%. At this point the rent showed a 22% predicted decrease. Total coverage required is 27%. Note that the cells selected are very similar those for C. **E.** As for D, but excluding only the trawl fishery from the MPA. Total coverage by MPA is 41%, the existence value predicted is 37% increase, and there was an 18% predicted decrease in total rent. Rent for fisheries other than trawl, however, increased by 21% at this point.

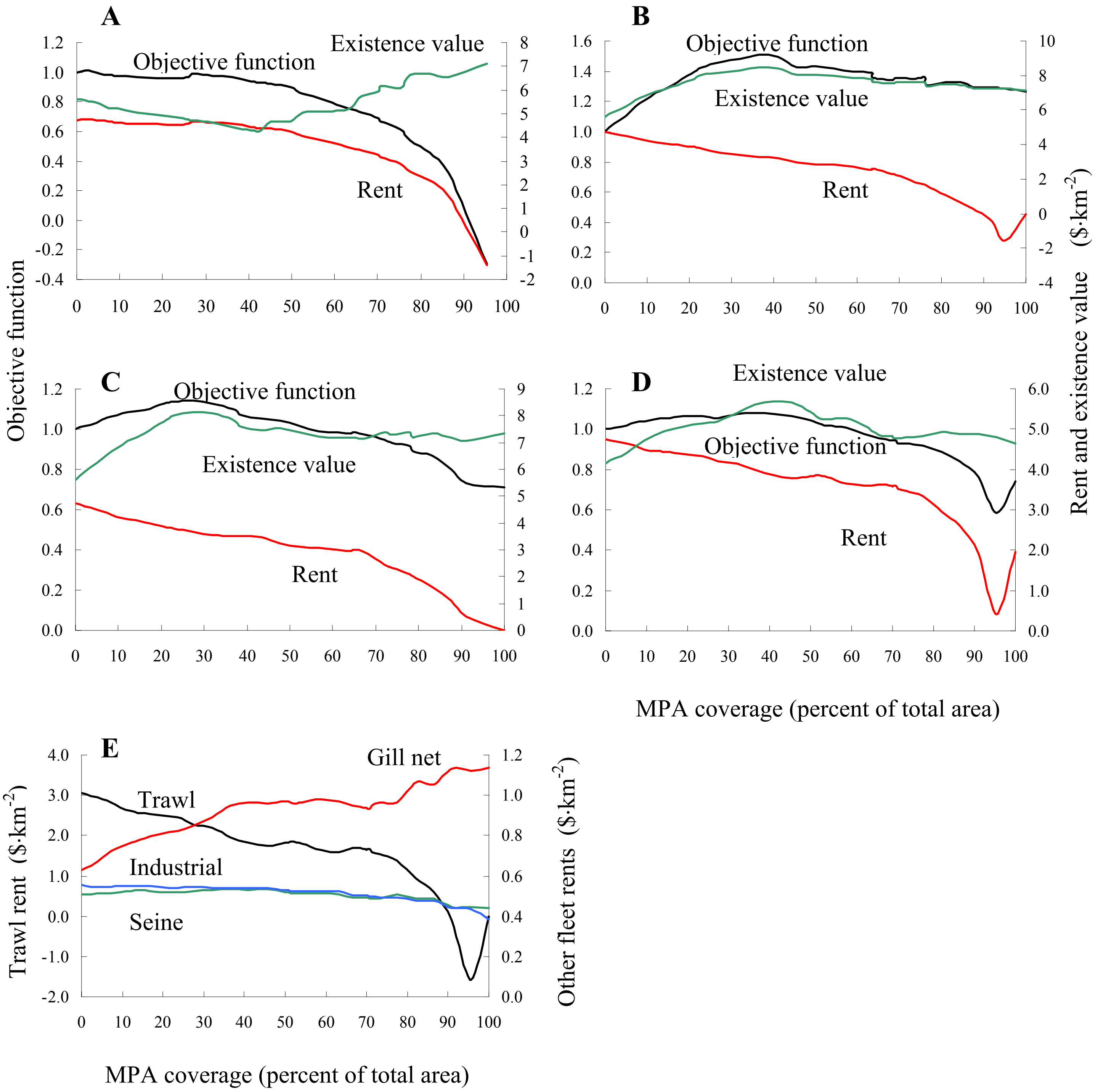

Figure 2. Values of the objective function, rent and existence value obtained under the different policies as a function of increasing MPA size, expressed as percent of the total area. **A.** Maximizing the objective function in terms of rent only. Fishery values decline by less than 5 % until greater than 40% coverage. No increased benefit to the existence value is predicted until greater than 65% coverage is achieved. **B**. Maximizing the objective function in terms of the existence value only. The largest increase in existence value was predicted in this game, however a peak is still predicted at 40% coverage. **C**. Maximizing the objective function in terms of the combined rent and existence value. The peak existence value occurs at 30% coverage, and the loss in rent is less than that predicted in B. **D**. As in C, but excluding only the trawl fishery from fishing in the MPA**.** The peak for the existence value is predicted at 50% coverage. The decline in predicted total rent is less than that for C. **E**. As in D, but showing the rents predicted for individual fleets. Note that only the trawl fleet has a predicted loss. For other fleets the predicted impacts are negligeable (Seine, Industrial) to large increases (Gill net).