INDIVIDUAL HABITAT QUOTAS FOR FISHERIES

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ABSTRACT

Fishery managers in the United States are required to identify and limit adverse consequences of fishing on essential fish habitat. We propose a cap-and-trade system for habitat conservation that would utilize economic incentives to achieve habitat conservation goals cost effectively. Individual quotas of habitat impact units (HIU) would be distributed to fishers with an aggregate quota set to maintain a target habitat "stock". Fishers would access a GIS database to determine the HIU they would be charged at each location and a vessel monitoring system would monitor HIU use. HIU use would be based on marginal habitat damage. We use a dynamic explicitly spatial fishery and habitat simulation model to explore the cost effectiveness of this system versus alternative means of achieving habitat conservation targets. Individual vessels are given quotas of both fish and HIU and are distributed to locations with the highest margin between HIU cost and revenue. The model uses an iterative approach to find the minimum price for HIU that allows fish quotas to be taken without exhausting all HIU. The cap-and-trade system is compared to habitat protection implemented through fixed or rotating closed areas by comparing the effort/cost required to take the total fish quota while maintaining a target habitat stock. Although the model effectively implements a tax based system, it represent the outcome of a quantity based system since the tax is determined endogenously by the quantity of HIUs and the distribution of the habitat and fish stocks.

Keywords: fisheries; individual quota; essential fish habitat; closed areas

INTRODUCTION

In 1996, the U.S. Congress added new habitat conservation provisions to the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). These changes came in response to concerns that habitat loss was threatening the viability of many of the nation's fisheries. The findings section of the MSFCMA states that "One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats." Ironically, much of the habitat damage in offshore areas is the result of fishing which can reduce the complexity of the benthic structure, increase the resuspension of benthic sediments, and alter trophic relationships within the ecosystem (Engel and Kvitek, 1998; Johnson, 2002; Pilskaln et. al., 1998). Deleterious effects of fishing on habitat of course vary with the intensity of activity, the harvesting technology, the habitat type and oceanographic conditions.

The MSFCMA directs the National Marine Fisheries Service (NMFS) and the eight regional fishery management councils to identify and describe essential fish habitat (EFH) in each fishery management plan; minimize to the extent practical the adverse effects of fishing on EFH; and identify other actions to encourage the conservation and enhancement of EFH. However, the protection of EFH must be considered within the context of the rest of the Act, which requires consistency with several national standards. National Standard 1 states that "Conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery for the United States fishing industry." Regulations promulgated by NMFS instruct councils to "consider the nature and extent of the adverse effect on EFH and the long and short-term costs and benefits of potential management measures to EFH, associated fisheries, and the nation" (50 CFR §600.815").

Unfortunately, determination of the net economic benefits from conserving and protecting EFH is probably not possible for most fisheries at this time. There is considerable uncertainty as to what effects protective actions will actually have on habitat and how long recovery of damaged habitat will take.[i] Even if the physical impacts on habitat were perfectly understood, valuing those impacts remains difficult. It is not generally adequate or appropriate to directly value the features of habitat. Although protection of specific components of the habitat (e.g., marine plants and animals such as corals and sponges) may generate non-use values which may be estimated with non-market valuation techniques, these benefits are arguably not the primary focus of the EFH provisions of the MSFCMA[ii]. The benefits from habitat protection are likely to be primarily indirect benefits resulting from increases in the productivity of fisheries, reduction of variability in production, reduction in the risk of fishery depletion or collapse, and reduction in the risk of species extinctions.

To the extent that EFH protections close areas to fishing or restrict certain fishing practices and gears to mitigate these impacts, they are likely to increase harvest costs. Cost increases may be offset in the long run if habitat protection increases the productivity of fish stocks thereby increasing fish availability. But even where increases in productivity occur they will not necessarily compensate for increased costs. A comprehensive review of empirical studies of marine reserves found “little documented evidence that in a well managed fishery, no-take reserves offer additional advantages to a fishery over and above those offered by better classical management techniques”(Ward, Heinemann and Evans 2001). Several published modeling studies of marine reserves and closed area for fisheries draw similar conclusions. They suggest that a correctly sized marine reserve may increase yields in fisheries that are subject to growth or recruitment overfishing, but that little if any yield increases can be achieved in fisheries where effort is already at the level that produces maximum sustainable yield or maximum yield per recruit (e.g., Beverton and Holt 1957; Hannesson 1998; Hastings and Botsford 1999; Holland 2003, Holland and Brazee 1996; Polacheck 1990; Sanchirico and Wilen 1999, 2000 and 2002; Smith and Wilen 2003).

In the absence of sufficient information to determine the optimal level and form of habitat protection, it may be more useful to concentrate on designing cost-effective systems of habitat protection. Careful design of MPAs may achieve some cost savings but is unlikely to be the most cost-effective means of providing a given level of habitat protection. Economic theory and experience in fishery management and environmental protection have shown that regulatory systems that rely on individual economic incentives and property rights to achieve targets, and allow flexibility in the means of achieving those targets, can greatly reduce the costs of achieving them. Rights based systems such as individual transferable quota (ITQ) systems have proven effective at increasing the profitability and sustainability of fisheries (OECD 1997).

ITQ systems alone will not mitigate externalities such as habitat impacts (Holland 2004), but it may be possible to extend rights based fishery management to achieve habitat protection goals. Experience in Australia with property rights for irrigation water has demonstrated the value of separating the property right for removals of water from a river or groundwater aquifer from negative outcomes such as salinity loading associated with its use (Young and McColl 2003). Young and McColl note that negative externalities associated with water use can vary with how and where the water is used. A separation of the rights for the negative impacts of water use from the quantity of water used will tend to lead to a shift of use to users with lesser external impacts per unit of water use. Thus a given level of abatement of those impacts can be achieved at lower cost than either reducing total water use or specifying consistent best management practices for all users. A similar approach might be taken with the habitat impacts of fishing. A correctly designed approach would lead to a distribution of rights that would equate the marginal costs of avoiding habitat damage across fishers thereby minimizing the cost of achieving a given level of habitat protection.

We believe that a cap-and-trade system for habitat impacts of fishing could be developed to deliver a given level of habitat protection cost-effectively. In this paper we describe how an individual habitat quota (IHQ) system might work. Individual quotas of habitat impact units (HIU) would be distributed to fishers with an aggregate quota set to maintain a target habitat “stock.” HIU use would be based on a proxy for marginal habitat damage based on area fished, and monitored and measured using a vessel monitoring system (VMS) that continually monitors vessels’ location and rate of movement. The habitat impact units (HIU) used by a vessel might differ with the type of gear and would be based on empirical studies of marginal physical damage associated with fishing particular gears in particular types of habitat. Each year a total number of habitat units would be allocated and would be transferable. Like most ITQ systems, quota holders would have an ongoing right to a proportional share of the total quantity of HIU allocated each year, but that quantity could be changed. The total quantity of HIU allocated each year would be set to maintain a given level of habitat protection as measured by the total remaining “stock” of HIU. A given total stock of HIU might be made up of a combination of totally and partially regenerated areas. The quantity of HIU allocated each year would depend on the regeneration time of habitat, the standing stock of habitat, and the target level of the habitat stock. However, the definition of HIU, setting the target stock and determining the total HIU quota would not require regulators to determine either the total or the marginal value of habitat protection. The market for HIU would reveal the implicit cost of habitat protection.

THE SIMULATION MODEL

We use a spatial fishery simulation model to explore how an IHQ system might work and evaluate how it would perform relative to a system of fixed or rotating MPAs. The simulation model is explicitly spatial with a fish stock, habitat and fishing effort modeled on a (25 x 40) two dimensional grid of 1000 cells. Following Sanchirico (2003) we use a honeycomb structure to model the physical connectivity of the cells in the grid with diffusion of the fish stock occurring over six equal edges of each cell. So that all grid cells have the same relative connectivity to other cells, we connect the edges of the grid (i.e., fish can move from the right edge to the left edge and from the top to bottom). While fish must move from one cell to the next, fishers can choose any cell to fish each fishing event. Our design would allow us to model explicit relationships of cell and port location that might affect relative harvest costs amongst cells, but, for our simulations, we assume homogeneous costs and productivity across all cells.

The Fish Population

The Fish population is modeled as a single cohort so that we need only track the weight of fish in each cell. The net change in weight of fish $x_{i,t}$ in each cell *i* each period *t* accounts first for harvests, then for growth and recruitment and lastly for net diffusion of fish into or out of the cell. The total catch from cell *i* in period *t* is determined by the removals by any of the *v* vessels in the fleet that choose to fish there. The vessel in the fleet are deployed consecutively and the population of the cell they fish in is adjusted after each vessel is deployed.

$$x_{i,t+1} = x_{i,t} - \sum_{v=1}^{V} q e_{i,t,v} x_{i,t,v} \tag{1}$$

where *q* is the catchability coefficient that determines the percentage of the cells fish population removed by one fishing event and $e_{i,t,v}$ is equal to 1 if vessel *v* fishes in cell *i* in period *t* and zero otherwise. Note that if one vessel chooses to fish in a given location, the population is reduced before the next vessel is deployed so that the catch by the subsequent vessel during the same period *t* would be lower than for the first vessel. We discuss how the location choice of each vessel is determined under the subheading "Fleet Dynamics."

Total annual population growth, *G*, is assumed to be a fixed proportion of the previous year's population biomass at the end of the final time step for year *T*.

$$G = \delta \sum_{i} x_{i,T} \tag{2}$$

where x_i is the fish biomass in cell *i* , and δ is the population growth rate.

We divide annual growth into growth from recruitment and growth of the existing population. While the spatial distribution of growth of the adult population must necessarily be correlated with the spatial distribution of the fish population, the spatial distribution of growth from recruitment may not be. This has important ramifications for policies which exclude (either through regulation or economic incentive) fishers from particular locations. If the distribution of population growth is tied directly to the distribution of adults, then spill-over benefits from the fish population inside a closed or unfished area will result only from emigration of adults from that area. Recruitment that is not spatially tied to the location of adults has the potential to decrease the cost of locking up part of the adult population in a closed area by creating additional spill-over well beyond its boundaries.

A parameter α determines the share of total annual population growth, *G*, that occurs through growth of adults versus the remainder of total growth in the form of recruitment. Growth of the adult population is distributed evenly throughout the year and amongst the cells in proportion to their share of the overall population. Growth from recruitment is distributed randomly, both over space and through the year.

$$x_{i,t+1} = x_{i,t} + \alpha \frac{G}{T} \frac{x_{i,t}}{\sum_{i} x_{i,t}} + (1-\alpha) G \frac{z_{i,t}}{\sum_{i} \sum_{t} z_{i,t}} \tag{3}$$

where *T* is the number of time steps modeled each year, *z* is a uniformly distributed random number with a value between 0 and 1 assigned to each cell and period.

Finally, net diffusion is modeled as:

$$x_{i,t+1} = x_{i,t} + d(\sum_{k=1}^{6} x_{k,t} - 6x_{i,t}) \tag{4}$$

where d is the diffusion rate and the $x_{k,t}$ are the population biomasses in the six cell surrounding cell *i*.

Habitat

The habitat stock $h_{i,t}$ in each cell is modeled very simply. We assume that each cell has a maximum habitat stock of h_{max} and that habitat regenerates at fixed absolute rate of *r* units per year up to the point where it has reached the maximum value. Much like the fish stock, the stock of habitat is reduced by consecutive removals by any of the *V* fishing vessels that are deployed there. Reduction of the habitat stock is a fixed proportion γ of the current habitat stock at the time a vessel fishes there:

$$h_{i,t+1} = h_{i.t} + \min[(h_{\max} - h_{i,t}), r] - \sum_{v=1}^{V} \gamma e_{i,t,v} h_{i,t,v} \tag{5}$$

where $e_{i,t,v}$ is equal to 1 if vessel *v* fishes in cell *i* in period *t* and zero otherwise. Note that if one vessel chooses to fish in a given location, the habitat stock is reduced before the next vessel is deployed so that the habitat reduction by the subsequent vessel during the same period *t* would be lower than for the first vessel.

Each year a total quota for habitat (THQ) is set equal to the projected habitat level at the end of the year in the absence of fishing less the target level for the habitat stock.

$$THQ = -H^{\text{target}} + \sum_{i} \left[\!\left[h_{i,t} + \min[(h_{\max} - h_{i,t}), rT] \right]\!\right] \tag{6}$$

Fleet Dynamics

Each year a TAC is set equal to the annual growth of the fish population *G* plus any residual unfished quota from the prior year. The model ensures that the fleet catches between 99.5 and 100% of the TAC, so the TAC remains roughly constant. The total habitat quota is set to maintain a target habitat stock and can change over time depending on the level of the habitat stock relative to the habitat target. The fish and habitat quota is divided evenly among the vessels. The model then determines the distribution of effort through a looping process. An initial price for HIU is set by the model and fishing vessels are distributed consecutively to areas with the highest margin between HIU cost and the relative revenue rates. We model the location choice decisions of the fishing vessels assuming they possess information about the present distribution of the fish stock and habitat, but that they are not forward looking. Each time period, the model consecutively distributes each vessel in the fleet to the most profitable location as determined by the predicted value of catch for that location minus the cost of HIU used to fish there:

$$\pi_{v,t} = p^f q x_{i,t,v} \exp(\sigma \varepsilon_{i,t}) - p^h \gamma h_{i,t,v} \tag{7}$$

where p^f is the price of fish and p^h is the price of HIU. The fish price is a fixed parameter of the simulation, but the HIU price is determined endogenously as we describe below. The term $\varepsilon_{i,t}$ is a normally distributed random number with a mean of zero and a standard deviation of one times the uncertainty multiplier *σ*. The larger the uncertainty multiplier, the greater is the uncertainty about the level of catch and revenue that will be realized by fishing in a particular location.

The vessel uses up fish quota equal to its catch $qx_{i,t,v}$ and HIU used by the vessel is equal to the removal of habitat stock $\gamma h_{i,t,v}$. However at the beginning of each period, the model redistributes quota equally among the fleet. This ensures that a minimum fleet size is needed to take the TAC and that individual vessels' fish and habitat quotas remain balanced. This is consistent with the operation of an efficient market for both fish and habitat quota. The model runs for one year with a price of zero for HIU. If the TAC is not taken due to the fleet running out of habitat quota, the price of HIU is increased and that year is simulated again. This looping process continues until a price for HIU is found which allows the fleet to take the TAC without exhausting the total quota for habitat.

For the MPA simulations, vessels are deployed to open locations with the highest expected catch rates at that time of each fishing event. In the simulations of the habitat ITQ program, the fleet size is set at the minimum size required to take the TAC. That fleet size remains constant over time. However for the MPA simulation, average catch rates change over time as the fish population becomes concentrated in the closed area over time. The MPA simulations allow the fleet size to change so that the fleet size remains the minimum size necessary to take the TAC.

Table 1: Model Parameters

Parameter	Value
Fish Growth Rate $\boldsymbol{\delta}$	0.20
Adult Growth Share of Total Growth $\boldsymbol{\alpha}$	0.50
Fish Catchability Coefficient $\boldsymbol{q}$	0.40
Habitat Catchability Coefficient $\boldsymbol{\gamma}$	0.80
Maximum Annual Habitat Regeneration Rate Per Cell $\boldsymbol{rT}$	$0.1*h_{max}$
Price of fish p^f	1.00
Diffusion Rates d	0.01-0.03
Uncertainty Multiplier σ	0.0-0.25
Fleet Size	10 for IHQ, Variable for MPA

POLICY EVALUATION

Each simulation begins with an initial distribution and size of fish population and habitat resulting from running the model for 20 years with a TAC equal to that used for subsequent years, but no habitat regulations. The IHQ model then sets an initial target for total habitat stock equal to the minimum of the final habitat target or the current habitat stock plus an increment of 10% of the virgin level. The habitat target is then increased in this way each year until it reaches the final habitat target where it remains for the rest of the simulation. The simulation runs a total of 50 years after implementation of the IHQ program

Like the IHQ simulations, the fixed MPA model is initialized by running the model with no habitat protection for 20 years. A vertical (25 x 40) strip of cells encompassing 20% of the fishery is then closed to fishing and remains closed for the 50 year duration of the model. The fleet size is increased over time by the minimum increment that allows it to take the TAC.

The rotating MPA simulations works similarly except that every ten years the 200 closed cells are opened to fishing and another 200 cells are closed. The new closure is a non-adjacent set of 200 cells. Over the 50 year period modeled each fifth of the grid is closed for 10 years. Note that all of the MPAs, whether on the edges of the grid or the interior, have an equivalent level of connectivity to open areas and a fishable perimeter of 50 cells since the structure of the diffusion process connects the left and right edges and top and bottom of the model.

To test the sensitivity of our results to key parameters we ran a suite of simulations with varied diffusion rates and uncertainty levels (Table 1). Previous work on MPAs has highlighted the importance of fish movement rates in determining impacts. We ran simulations of each management strategy with diffusion rates varying from 0.01 to 0.03[iii]. A diffusion rate of 0.01 implies that a maximum of 1% of the population within a cell migrates to each of the 6 surrounding, a total of 6%, and for 0.03, 3% migrates to each surrounding cell, a total of 18%. This diffusion occurs at each time period within the simulation and there are fifty time periods per year thus even the lowest diffusion rate can result in substantial migration between cells. Net migration between cells of course declines, the closer the size of the fish population in adjacent cells.

Another key parameter that can be expected to affect performance of the IHQ regime in particular is uncertainty about the location of fish. We vary the uncertainty level, σ, from 0 to 0.25. Roughly speaking, when the uncertainty multiplier is set to 0.025 the predicted catch of a location ranges from 96-105% of what the true catch would be 95% of the time. With the uncertainty multiplier set at the upper range of 0.25, the predicted catch ranges from 62-163% of the true value 95% of the time.

Empirical studies show that marginal damage rates and recovery rates vary greatly depending on the type of habitat and the type of fishing gear as well as for particular types of sessile organisms in a given habitat (NRC 2002). We use a marginal damage rate of 80% and an absolute recovery rate of 10% or the maximum HIU stock per year. This is a relatively high rate of marginal damage and a low rate of recovery relative to many habitat types fished by mobile bottom tending fishing gear (NRC 2002), suggesting that the simulated performance of the habitat protection systems, and the IHQ program in particular, may be understated.

RESULTS

CPUE as a Measure of Cost-Effectiveness

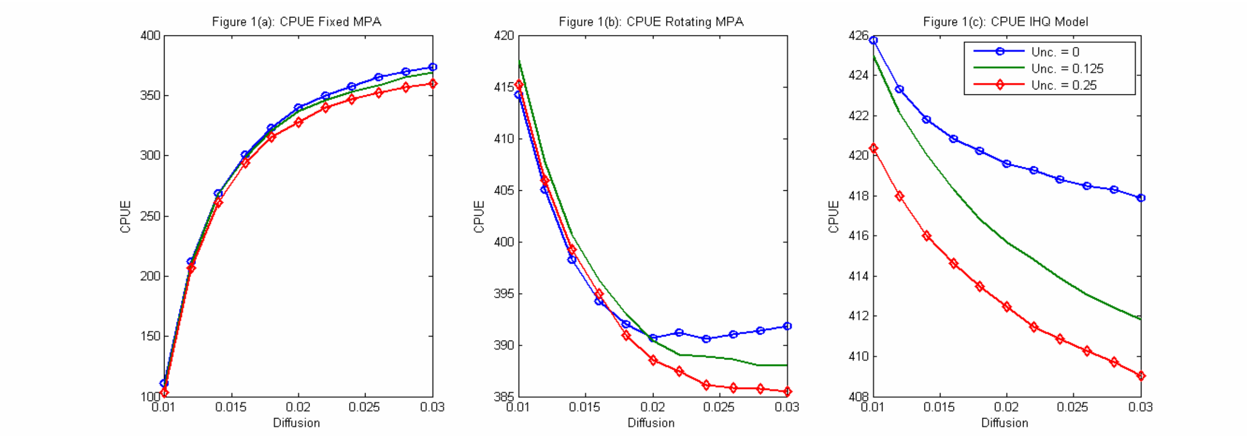

Figure 1: CPUE as a function of diffusion rates and uncertainty for IHQs, Fixed MPAs and Rotating MPAs

CPUE is our primary indicator of the relative cost-effectiveness of the three alternative management regimes. Since the total allowable catch (TAC) is the same in each of the three models and effort is adjusted to the level necessary to take the full TAC, a change in CPUE directly correlates with a change in nominal fishing effort. Higher CPUE means both lower cost per unit of catch and a lower total cost of harvesting the TAC. Of the three management strategies, the IHQ system results in the highest CPUE regardless of the diffusion rate or uncertainty level (Figures 1a-c). Rotating MPAs results in a higher CPUE than fixed MPAs for all levels of diffusion and uncertainty.

Although the relative ranking of the management systems in terms of CPUE is robust to the range of diffusion rates simulated, the diffusion rate is clearly an important determinant of performance for all three management systems and affects them differently. The diffusion rate has only a small impact on CPUE for the IHQ system (Figure 1c). As diffusion rates increased, the population becomes more broadly dispersed, decreasing the ability of the fleet to target areas where stocks are highly concentrated. CPUE consequently declines whether or not the fleet is attempting to avoid areas with high habitat quality.

For fixed MPAs the rate of diffusion rate has the opposite and a much more dramatic effect on CPUE (Figure 1a). With the lowest rate of diffusion (0.01), CPUE is less than 25% of that which results with either IHQs or rotating MPAs. Increasing the rate of diffusion for 0.01 to 0.03 causes the CPUE to increase by as much as 250% depending on the uncertainty level. When the rate of diffusion is low, the population lying within the MPA is constrained to the MPA and therefore does not augment the fishery via migration. As the diffusion rate increases migration out of the MPA increases resulting in a higher CPUE for the fleet which in heavily concentrated along the edge of the MPA. This result clearly illustrates that, for relatively immobile species, fixed MPAs are a highly inefficient means to provide habitat protection.

Perhaps surprisingly, higher diffusion tends to decrease CPUE for rotating MPAs (Figure 1b). With a low rate of diffusion, little of the protected population diffuses into the fishing grounds causing a rapid build-up of the population inside the MPA and decreasing the CPUE outside it. However, when the rotation occurs, the CPUE immediately, and dramatically, increases as effort floods in to the previously protected area where the fish have become concentrated. When calculating the average CPUE over the entire simulation the advantage of the very high

CPUE levels after reopening, that result with low diffusion rates, outweighs the lower CPUE that occurs in the intervening years.

While a lower diffusion rate tends to increase the average CPUE level for rotating MPAs, it also leads to much larger fluctuations in the total effort required to take the TAC. The model adjusts the fleet size to the minimum required to take the TAC. With the lowest diffusion rate, the fleet size rises to 12-13 vessels just before the rotation and immediately drops to five following rotation. This presents an additional policy concern. It may be necessary to maintain a larger fleet capable of catching the TAC when CPUE is low. In addition, excess capacity that occurs when CPUE is high, may flow into other fisheries which may pose sustainability risks if catches is those fisheries are not constrained.

Increasing uncertainty in relative profitability of fishing locations tends to decrease CPUE for all three models[iv] but the effect is not large and does not affect the relative rankings of the management systems with regards to CPUE. Over the range of diffusion rates implemented, the percentage change in CPUE resulting from increasing the level of uncertainty from 0 to 0.25 ranges from -7.29% to -3.63% for the fixed MPA model, 0.03% to -1.4% for the rotation MPA model, and -1.27% to -2.12% for the IHQ model (Figures 1a-c).

Habitat Quality

The alternative management regimes have quite different impacts on average habitat quality and the spatial distribution of the "habitat stock." The IHQ regime is designed to maintain a particular level of average habitat quality but essentially leaves the distribution of the habitat stock to the fleet. In the base case simulations, average habitat quality is maintained at 30%. The IHQ system tends to result in a highly dispersed patchwork of unfished areas surrounded by fished areas. Although average habitat quality remains unchanged, the number of areas with the maximum habitat stock (which occurs if an area has not been fished for at least 10 years) declines with higher levels of diffusion and uncertainty though the target 30% habitat stock is maintained.

Average habitat quality with fixed MPAs varies between 20% and 40% depending on the level of diffusion and uncertainty (Figure 2a). With the lowest diffusion rate, average habitat quality for the entire grid is maintained at a minimum of 20% by the MPA, but average habitat quality outside the MPA approaches zero. As the diffusion rate increases from 0.01 to 0.03, the average habitat quality with fixed MPAs increases to 40%. This is a direct result of the decreasing level of effort required to take the TAC. With low diffusion rates the fleet size is nearly five times that with the lowest diffusion rate and more than five times the fleet size required with the IHQ system in place. This results in nearly every open location being fished at some point in the year even though most of the fleet is concentrated along the perimeter of the MPA. The fleet size with the highest diffusion rate is only 20% larger than the IHQ fleet. Uncertainty has an opposite, but a less pronounced, effect, decreasing average habitat quality by as much as 5% below what is achieved with no uncertainty.

The range of average habitat quality achieved with rotating MPAs also straddles the 30% target for the IHQ system (Figure 2b). As with fixed MPAs, higher diffusion rates lead to higher average habitat quality. Even though the average CPUE is lower with higher diffusion rates, the fleet size does not expand as much leading up to rotation and effort remains more concentrated on the perimeter of the MPA due to higher leakage from it.

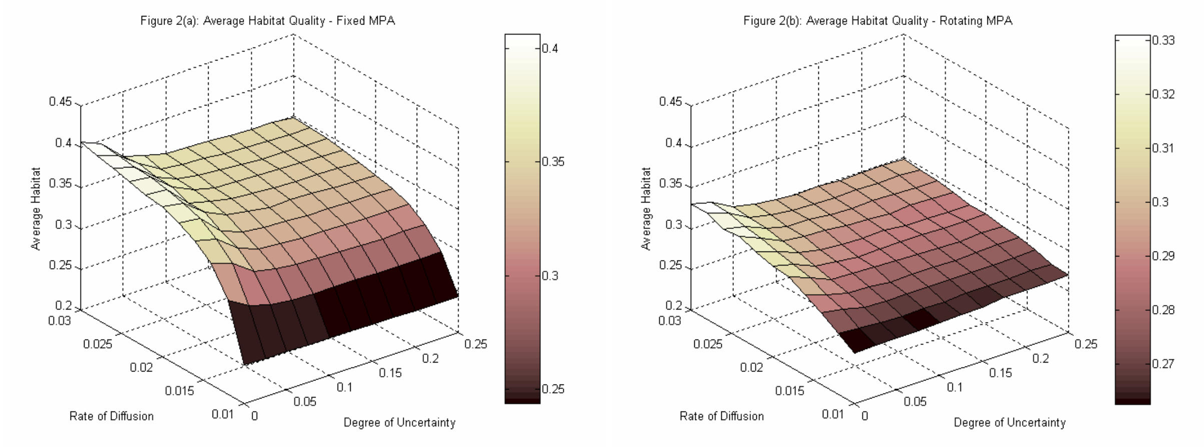

Figure 2: Average habitat quality as a function of diffusion and uncertainty with fixed and rotating MPAs.

An important aspect of the rotating MPA system is that the level of habitat protection varies not only spatially but temporally. The temporal pattern of habitat conservation is illustrated by considering the average level and distribution of habitat quality at the end of years 19 through 22 (Figure 3). The habitat quality of individual cells inside the MPA increases to a maximum level by year 20 (the end of the ten year closure). However after rotation, the habitat quality inside the previously closed area declines quickly. In year 21 the habitat in the middle of the MPA, where the fish population is highest, is reduced to a level below 10% of pristine and by year 22 the entire MPA is reduced to this level. Over the 50 year simulation period, habitat quality in nearly every location is reduced to low levels following reopening of each successive MPA. Average habitat quality also fluctuates, falling substantially in the 2-3 years after rotation and then rebuilding until the next rotation.

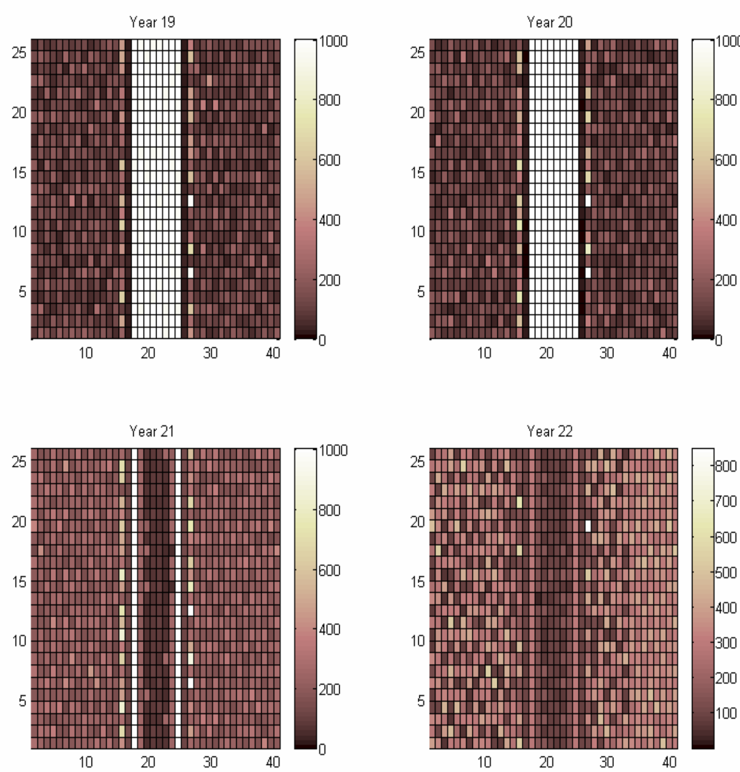

Figure 3: Spatial distribution of habitat stock for rotating MPA at the end of years 19-22.

With a habitat target of 30%, the IHQ system always provides higher CPUE than fixed or rotating MPAs, but the level of habitat protection (measured in terms of average habitat quality) is higher with MPAs if diffusion rates are high. This raises the question whether higher levels of habitat protection could be achieved with the IHQ system while still maintaining better economic performance. A striking result is that CPUE is not greatly reduced by increasing the habitat target and the CPUE within the IHQ model is always above that achieved with rotating and fixed MPAs for habitat targets less than or equal to 50% (Figure 4). The IHQ system is a win-win solution, achieving a higher level of habitat protection at a lower cost than either the fixed or rotating MPAs.

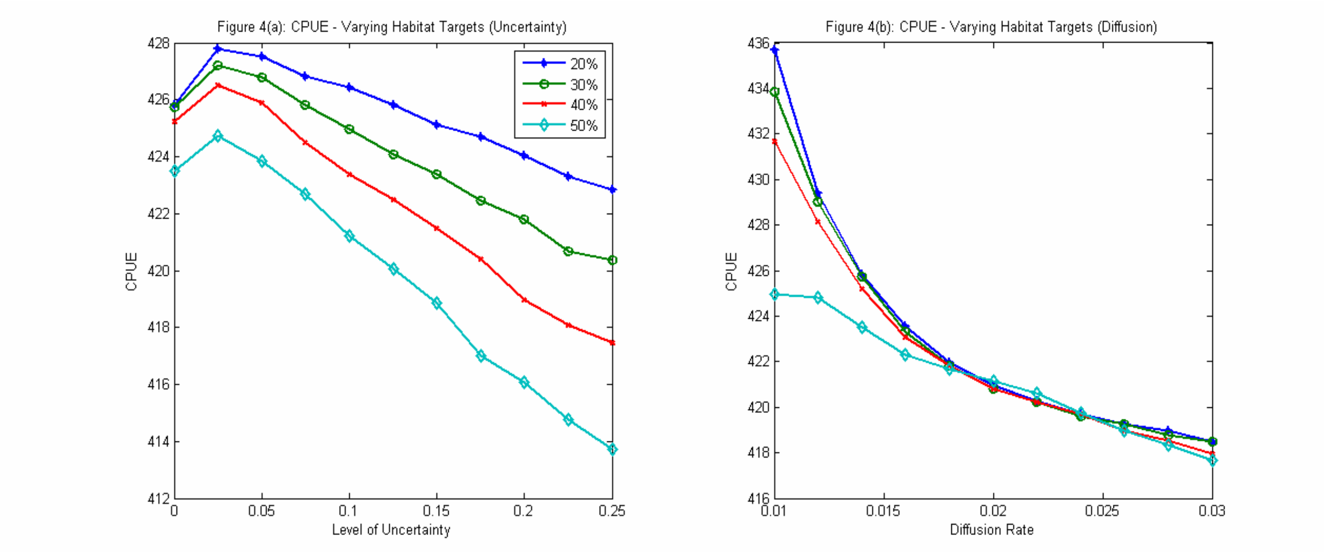

Figure 4: CPUE for IHQ with varied habitat targets, uncertainty levels and diffusion rates.

The Price of Habitat Impacts Units

The IHQ model sets a price for HIU just high enough to ensure the TAC is taken without exhausting the total habitat quota. From a public benefit-cost perspective the price of habitat quota may be irrelevant since it only results in an income transfer from those who use quota to those who own it. However, from the perspective of the individual who may have to purchase HIU or may have the opportunity to sell or lease his allocation, the price may be of great importance. If the cost of HIU is high relative to the value of catch, managing one's HIU holdings and use will become an important part of overall business strategy. Therefore, it is of interest to examine how the price of HIU is affected by diffusion rates, uncertainty levels and the habitat protection target.

Uncertainty has the strongest effect on HIU price. Depending on the diffusion rate, the price of HIU is 30-50 times greater for the highest levels of uncertainty (0.25) compared with no uncertainty (Figure 5a). As noise in the expected catch rates for different locations increases, an increasingly strong disincentive is required to make fishers avoid areas with high habitat quality. The disincentive created by a surprising low HIU price is sufficient to change behavior when there is little uncertainty. In simulations with the lowest diffusion rate, no uncertainty and a 30% habitat target, the maximum cost of habitat units incurred (i.e., from fishing in a location with pristine habitat) amounts to little more than 1% of the average revenue associated with each location choice. However, as uncertainty is increased, the disincentive of the HIU price is swamped by noise in expected catch rates. With the highest level of uncertainty (0.25), the lowest diffusion rate (0.01) and a 30% habitat target, the maximum cost of habitat units incurred amounts to nearly 35% of the average revenue.

Higher diffusion rates tend to have the opposite and a less pronounced effect on HIU price (Figure 5a). Higher diffusion rates tend to reduce the relative difference in concentration of fish between recently fished areas with low habitat quality and areas that have not been fished and have higher habitat quality. Since the relative catch rate advantage of fishing in these areas with higher habitat quality is smaller the monetary disincentive required to make fishers avoid them is also lower. At the lowest uncertainty levels, the price of HIU with the lowest diffusion rate is over 3 times that with the highest diffusion rate. At the highest uncertainty rate, the ratio of HIU prices with low vs. high diffusion rates falls to 1.7.

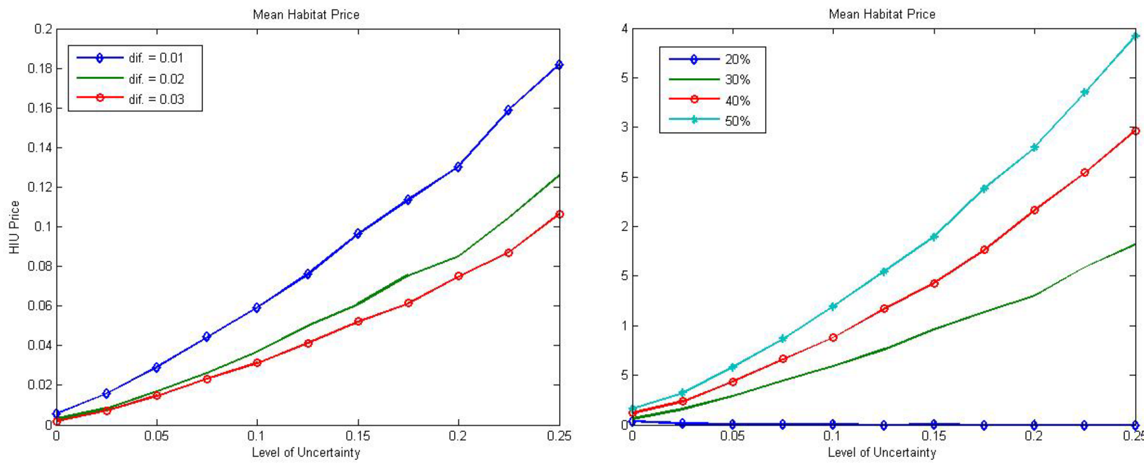

Figure 5(a): Average HIU price as a function of uncertainty and diffusion with 30% habitat target

Figure 5(b): Average HIU price as a function of uncertainty and habitat target with lowest diffusion rate

As one might expect, the HIU price is also increased as the habitat target is increased. The percentage increase in HIU price is more than proportional to the increase in the habitat target (Figure 5b), but the effect of the habitat target is relatively minor compared to the effect of uncertainty. In simulations with the diffusion rate set at the minimum level (0.01), increasing the habitat target from 30% to 50% increases the price of HIU by 2-3 times depending on the uncertainty level with the greater percentage increase occurring at lower levels of uncertainty. In contrast, increasing uncertainty to the highest level of 0.25 causes the HIU price to increase to 19-32 times the price with no uncertainty with greatest difference in HIU price occurring in the middle of the range of habitat targets.

SUMMARY AND CONCLUSIONS

It may be some time before we are able to quantify the benefits of habitat protection, yet it will probably be necessary to ensure some level of habitat protection without fully understanding the benefits of doing so. Consequently there is a need to develop cost-effective ways of achieving a given level of habitat protection. Our analysis suggests that extending rights based fishery management to include habitat impacts as a separable property right appears to be an efficient and effective means of achieving habitat protection. Our proposed IHQ system would achieve habitat protection objectives similar to MPAs; however, it would allow much greater flexibility in achieving the targets for protected habitat and do so at lower cost. Furthermore, the performance of the IHQ system is not greatly affected by fish movement rates while the cost-effectiveness of fixed MPAs is very sensitive to this parameter. This is important since fish movement rates are rarely known and are likely to vary across different target species that co-occur in the same region.

MPAs, whether fixed or rotating, are unlikely to achieve an optimal spatial-temporal distribution of fishing and habitat protection in terms of the trade-off between the marginal contribution to the habitat protection objective and the opportunity cost of closing a particular location to fishing. The inefficiency is likely to increase the longer an MPA remains closed as a larger proportion of the overall fish population becomes concentrated in the closed areas. It is clear that the cost of fixed MPAs will be lower if diffusion of fish out of the MPA is higher. While diffusion rates are clearly related to fish behavior, they are also impacted by MPA design. The IHQ system essentially creates a large number of very small MPAs. The cost-effectiveness of a large system of small fixed MPAs might begin to approach that of an IHQ system though it might also increase compliance costs.

Rotating MPAs are likely to be more cost-effective than fixed MPAs when fish movement rates are low, but they are also likely to result in a cyclical bust-and-boom pattern that will cause the fleet size to increase over time as catch rates fall followed by either greatly shortened seasons or decreased fleet sizes following the opening of the formerly closed area. Furthermore, the overall level of habitat protection will drop substantially after each rotation and then build up slowly over time. In contrast, an IHQ system allows the individuals with the greatest knowledge of the relative opportunity costs of not fishing in each location to choose a cost-minimizing patchwork of habitat protection that can be adjusted over time as the distribution of fish changes. In addition it allows for the maintenance of a steady level of habitat protection and a consistent level of fishing capacity and profitability over time.[v]

Although the results of the simulations suggest that the IHQ system is the most cost-effective means of achieving a given average habitat quality, it results in a very different spatial pattern of habitat protection than either fixed or rotating MPAs. Fixed MPAs provide permanent protection to a large contiguous area but result in low habitat quality outside the MPA. The IHQ system results in a dispersed patchwork of locations with high habitat quality. The rotating MPA also provides a large contiguous area of protection at a lower cost than a fixed MPA, but habitat quality is reduced to low levels in all locations at some point during the rotational cycle. The benefits of one type of protection versus another are likely to depend on objectives and factors not explicitly explored in this study. For example the relative advantages of MPAs would presumably be greater if habitat dependent species require large areas of contiguous high quality habitat. Alternatively, the IHQ system might reduce the risk of extinction of habitat dependent species that are widely dispersed or whose location is unknown.

An IHQ system may impose significant up-front costs to install the required monitoring system. But those costs must be compared to the costs that would be incurred by an alternative method of achieving habitat objectives such as fixed or rotating MPAs or gear restrictions, including both increased harvest costs and enforcement costs. Costs and feasibility of the IHQ system will also depend on the average size of vessels; it will be more expensive for a large fleet of small vessels than for a small fleet of large ones. However, our results suggest that the cost savings of the IHQ system will be significant in some cases, particularly in comparison to large fixed MPAs which allow relatively little leakage into the fishery or for species with limited movement.

Another potentially serious problem with a habitat ITQ system as described here is that it will reveal information about the fishing locations chosen by other fishers in real time as the GIS database of habitat stock is updated. It will not, however, reveal the location choices of specific vessels or their catch rates. The IHQ system will also generate a wealth of valuable information about the actual distribution of fishing activities that could be used to empirically evaluate the impacts of fishing on habitat and the recovery rates of unfished areas. Preserving the individual's freedom to choose where he or she fishes and producing the information necessary to understand and manage the impacts of fisheries on marine habitat cost-effectively may well require a sacrifice of privacy.

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ENDNOTES

[i] The recovery rate of habitat will depend on structure of the benthic community disturbed. For an in depth review of the different recovery rates one should read Johnson (2002) and citations therein.

[ii] Other legislation, the Endangered Species Act in particular, may require protection of particular animals or plants but generally does not require a balancing of the costs and benefits of doing so.

[iii] With diffusion rates below 0.01, the fleet could not continue to catch the TAC with a fixed MPA regardless of the fleet size.

[iv] The only exception to this is for low levels of diffusion within the rotating MPA model, where the marginal effect is negligible.

[v] Regardless of whether some form of habitat protection is implemented catch rates, total catches and profitability will fluctuate over time due to natural variations in recruitment and growth. This natural variation will not be eliminated by an IHQ program but should not increase it as a system of rotating MPAs would be expected to do.