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Marine protected areas in a welfare-based perspective

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ABSTRACT

Assuming a broad set of fisheries management goals, this paper analyzes the implementation of a marine protected area (MPA) together with open access outside, applying a bioeconomic model that ensures unchanged growth post-MPA. Taking into account that conservation and restoration, food security, employment and social surplus are amongst the objectives that many managers include in fisheries management, it is found that this broader welfare economic approach to MPAs may well recommend them to a greater degree than espoused in the more common resource rent focused studies carried out to date. It is shown that for overfished stocks, an MPA may yield resource protection, maximize harvests and increase consumer and producer surplus, as well as give higher employment. This, however, is less apparent for moderately overfished as well as highly migratory stocks. Resource protection and enhancement implicitly improves ecosystem services.

1. Introduction

In the fisheries and development economics literature there is currently a debate over the right approach to fisheries management in developing countries. On the one side is found what is often referred to as the wealth-based approach [1,2], taking the standard microeconomic approach stating that effort has to be restricted in order for a fishery to generate rent, which then can be used to improve livelihood conditions. On the other side is found what has been referred to as the welfare approach [3–6], claiming that for very poor countries, the benefits from open access fisheries in terms of food security, as an income source and as a labor market buffer may outweigh the benefits of generating resource rent by restricting access. It is not the latter group's claim that the access to fisheries in developing countries should remain unrestricted forever, but that care should be taken in the transition. Béné et al. [4] state that the reduction of fishing capacity should be driven by pull factors such as growth in the remaining economy, rather than push factors such as exclusion by laws and regulation, and uses Norway as an example of a case where this has successfully occurred. Wilson and Boncoeur [5] point to the fact, demonstrated in several papers, that there is a correlation between countries with rich resource endowments and poor governance, a situation often referred to as the resource curse. They use a macroeconomic model to show that if mechanisms for redistribution of accrued resource rent are lacking and if the government has a higher tendency to spend money on unproductive import goods than the rest of the population, the efficient solution will deviate in the direction of higher fishing effort than what is found when using a partial equilibrium model to analyze the fishing sector alone.

The following expands upon the literature mentioned above and argues that marine protected areas (MPAs) in combination with open access outside in the harvest zone (HZ), may be coherent with the welfare approach: they may, given some fundamental biological and economic characteristics, ensure maximum sustainable yield (*MSY*) and provide protection of resources. Hence they function as a policy instrument contributing to food safety and employment, while at the same time providing economic benefits in terms of increased consumer and producer surplus, as well as contributing to protection of the biotic and non-biotic marine environment. On the cautionary side, this paper argues that the use of MPAs may complicate the path towards other types of regulations that could generate resource rent. This due to the fact that the introduction of an MPA may increase the equilibrium effort level in the fishery as compared to the purely open access case.

MPAs have been much addressed in the fisheries literature and they have, generally, been embraced by biologists as a potent tool in fisheries management and conservation (see e.g. [7,8]), while receiving a fair amount of skepticism from economists (see e.g. [9–11]). Biologists have claimed that economists fail to take the complexity of the ecosystems into account in their analysis, thereby underestimating the potential benefits from creating MPAs, while economists accuse biologists of applying too simplistic models of human behavior (see e.g. [12,13]) and as a result overestimating the benefits.

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Some of the skepticism expressed towards MPAs may have been based on the choice of growth model and management objective. Flaaten and Mjølhus [14,15] showed that the type of model used by e.g. Hannesson [9] and Sanchirico and Wilen [16] implies that post-MPA growth will be lower than pre-MPA growth, independent of any harvest. With this property built into the models used to evaluate the effect of an MPA, it should come as no surprise that a reserve is found to be costly in terms of fisheries. Though some studies have paid attention to harvest and conservation goals [10], most economic analysis of MPAs has focused on simple single-stock models without taking into account broader ecosystem or conservation values (see [17–20] for some exceptions). It should be admitted that conservation may be a goal in itself, meriting the study of target stock levels, as well as habitat restoration.

Within fisheries economics, analyzing management strategies to maximize resource rent is a central issue, but consumer and producer surplus (CS and PS respectively), the importance of which was illustrated in Copes' [21] seminal article, are also central elements of total economic surplus. Conditions under which an MPA can contribute to a change in PS and CS are suggested in Pezzey et al. [22] and mentioned in Sanchirico and Wilen [10], but are not included in their modeling. Hence, although economists often compare private property regimes or pure open access to MPAs in combination with open access [9,16,23], hardly any effort has been made to analyze when CS and PS will be generated and to what extent. This paper revisits the issue of the economics of marine protected areas using a model that does not assume lower biological growth through the introduction of a reserve, and extends the literature by focusing on other welfare economic benefits than solely resource rent.

The article is structured as follows: in Section 2 the model used for the analysis is presented. Section 3 isolates the conditions under which an MPA can be beneficial in terms of stock protection, harvest, employment, as well as consumer and producer surplus. Section 4 provides discussion, while Section 5 presents concluding remarks and policy recommendations.

2. The model

The model used is developed by Flaaten and Mjølhus [14,15], based on the logistic growth model. This section presents the parts necessary for the current analysis. Important characteristics of this model are that it ensures the same growth and yield potential pre- and post-MPA (denoted model A in Flaaten and Mjølhus [14,15]).

2.1. Pre-MPA dynamics and yield

The pre-MPA population is assumed to grow logistically and growth is given by

$$\dot{S} = rS(1-S) - Y, \tag{1}$$

where S is population size normalized by setting the carrying capacity equal to unity. Patchiness and ecosystem issues are disregarded and the habitat of the resource is a homogenous area, also equal to unity. The intrinsic growth rate is r and Y is the harvest, assuming that harvest can be described by the Schaefer catch function, $Y=rES$, where E is fishing effort, scaled such that the catchability coefficient equals the intrinsic growth rate.[1] This harvest function will be used later (see the last expression in Eq. (3)), but using stock density in the fishing zone rather than the total stock density. Pre-MPA S represents both the population size and density in a population distribution area of unit size. With the introduction of a reserve and a harvest area below, the population density in the harvest zone enters the harvest function instead of the total population.

2.2. Post-MPA population dynamics and yield

The carrying capacity as well as the habitat area is, as noted above, equal to unity in this modeling approach. When an MPA is established it means that a fraction of the carrying capacity and the habitat is set aside for protection from fishing and other activities that could harm natural growth. This fraction is denoted m and is the size of the MPA relative to the habitat area. Introduction of an MPA of size m, a harvest zone (HZ) of size $1-m$ and assuming density dependent migration between the two areas alters the dynamics to

$$\dot{S}_1 = r\left[S_1(1-S_1-S_2) - \gamma\left(\frac{S_1}{m} - \frac{S_2}{1-m}\right)\right] \tag{2}$$

$$\dot{S}_2 = r\left[S_2(1-S_1-S_2) + \gamma\left(\frac{S_1}{m} - \frac{S_2}{1-m}\right) - E\frac{S_2}{1-m}\right]. \tag{3}$$

S_1 denotes population in area 1, the MPA, S_2 the population in area 2, the HZ, E fishing effort and $\gamma=\sigma/r$, where $\sigma > 0$ is the migration coefficient. Thus γ, the relative migration rate is the ratio of the migration coefficient to the intrinsic growth rate. Note that the population density in the HZ, and not the total population density, now enters the harvest function as shown in the last term in Eq. (3).

The sustainable yield in the case of an MPA is

$$Y(S_1, S_2) = r(S_1+S_2)(1-(S_1+S_2)). \tag{4}$$

Thus sustainable yield is determined by the total stock, benefiting from the spillover to the harvest zone from the MPA.

2.3. Economic model

Unit price of harvest and cost of effort is assumed[2] to be constant and the profit can thus be described by

$$\pi = pY - C, \tag{5}$$

where p is the price per unit harvest and C is the total cost. Two different price and cost functions are used. First, to keep it simple a constant price of fish and a linear cost function with $C=aE$ are used throughout most of the analysis, where a is the unit cost of effort, including the opportunity cost of labor and capital as well as normal remuneration of owner capital. Second, to address the issue of consumer surplus, a downward sloping demand is required and the form used is $price=p-\beta Y$ in Section 3.4. For the discussion of producer surplus in Section 3.5, a convex cost function is required, and the form chosen is the quadratic $C=\alpha E^2$, knowing that any form could do as long as the marginal cost increases with effort. Thus any $C=\alpha E^a$, with $a>1$, may be used. Possible implications of this for the results are discussed in Section 3.5.

Under open access, effort is adjusted in proportion to profit according to

$$\frac{dE}{dt} = \mu(AR(E) - MC(E)), \tag{6}$$

where μ is the effort response parameter, $AR(E)$ is the average

[1] Biologists often use the harvest function $Y=FX$, with F as the instantaneous fishing mortality. In bioeconomic models in this and many other papers the product $qE=rE$ corresponds to F. The choice of scale for E is just a matter of convenience and in this analysis a catchability coefficient equal to r makes some of the equations and expressions simpler.

[2] These assumptions are relaxed in Sections 3.4 and 3.5.

Table 1
Parameter values used.

Parameter value	Low	High
c	0.15	0.45
γ	0.3	0.7
m	0.25	0.75
α	0.035	0.164

revenue as a function of effort and $MC(E)$ is the marginal cost of effort. Equilibrium under pure open access requires that (1) and (6) both equal zero, while for an MPA and open access equilibrium in HZ it is required that (2), (3) and (6) all equal zero. In the pre-reserve case when both price p and unit cost of effort a are constant, equilibrium stock level and fish density will be $S=c=a/pr$ and equilibrium effort will be $E=1-c$. In the case of an MPA and open access HZ the stock level in the harvest zone will be $S_2=c(1-m)$. Note that the fish density at open-access equilibrium is the same pre-reserve and post-reserve. The steady state stock levels in the case of a downward sloping demand or non-linear costs will be addressed in Sections 3.4 and 3.5 respectively.

2.4. Parameter values

Parameter values used for figures and illustrations are listed in Table 1. The analysis is restricted to fisheries where the stock is biologically overfished, implying that the pre-MPA stock level is less than 50% of the carrying capacity. Two cases are chosen, one in which the stock is severely overfished and at only 15% of the carrying capacity, and one in which the stock is lightly overfished, with equilibrium stock level at 45% of carrying capacity.[3] The analysis is restricted to cases where an MPA will be sufficient to protect a stock from extinction even in the case of zero cost harvesting – when γ, the ratio of the migration coefficient and the intrinsic growth rate of the stock is less than 1. If $\gamma>1$, an MPA alone will not be sufficient to protect a stock from extinction in the zero cost case ([15], Theorem 1). As the value of this parameter is significant for the results, two different values are used; $\gamma=0.3$ and $\gamma=0.7$, recalling that $\gamma=\sigma/r$.

3. What can be achieved with an MPA?

3.1. Conservation and restoration

Conservation of fish stocks may be an objective in itself, for example to reduce the risk of extinction or to ensure non-use and/or option values of the resource. Non-use values incorporate existence and bequest values, such as the pure valuation of the existence of natural resources or the willingness to pay to leave resources for future generations. Option values are the willingness to pay to ensure possible future values of the resources.

For use value the pertinent question is what difference can an MPA make if there are open-access fisheries outside the reserve? This question can be addressed from two angles. First, what limit to effort is necessary to assure a given minimum level of the fish stock? Taking this approach E can be treated as an exogenous variable. Second, how does equilibrium fishing effort change as a consequence of an MPA? This question requires treating E as an endogenous variable. The former question will be discussed in this section and the latter will be addressed in Section 3.5.

[3] Recall that the pre-MPA open access equilibrium stock level is $c=a/pr$.

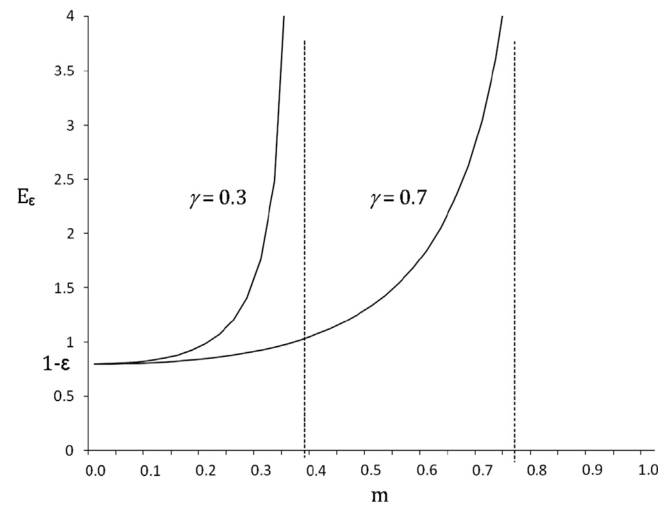

Fig. 1. The critical effort for precautionary stock level, E_ε, is a fraction of reserve size, m, and relative migration, γ. It has an asymptote which value also depends on γ, equal to $\gamma/(1-\varepsilon)$.

To keep the stock above a precautionary level, say ε, there is an upper effort level denoted the precautionary effort level, E_ε, which cannot be exceeded on a permanent basis. Under pure open access the precautionary effort level will be $E_\varepsilon=1-\varepsilon$. This precautionary effort level in the MPA case can be found by using (2) and (3) (see [14] for more details):

$$E_\varepsilon=1-\varepsilon+\frac{m(1-\varepsilon)}{\gamma/m(1-\varepsilon)-1}. \quad (7)$$

Thus E_ε depends on the precautionary stock level ε, the intrinsic growth rate and the migration rate included in γ, as well as the reserve size m. Note that when m approaches zero, E_ε approaches $1-\varepsilon$, and E_ε has an asymptote for $m=\gamma/(1-\varepsilon)$.[4] This is illustrated in Fig. 1 for $\varepsilon=0.20$ for two values of γ – the asymptotes are equal to 0.375 and 0.875, for γ equal to 0.30 and 0.70, respectively. A large reserve can sustain a high fishing effort without jeopardizing the targeted stock level ε.

The upward sloping E_ε curves in Fig. 1 illustrate the tradeoffs between effort and reserve size as possible management instruments. However, when using the MPA approach, the economic and catch efficiency characteristics of the HZ open-access fishery determine the effort level. Thus fishing effort is an endogenous variable also in the MPA case, as it is under pure open access. This implies further that the restoration of a depleted stock becomes easier with a reserve than without.

Bioeconomic models of fisheries largely focus on single stock management, though some attention is being paid to multispecies [24–27] and ecosystem [20] interactions. Nonetheless, scant attention has been afforded how fishing may affect the habitats that the fish live in, and how this again may affect the stocks that the fisheries depend upon [28]. Studies have shown that for instance trawling on some ocean habitats may lead to poorer condition in individual fish, and lower weight at age, which again reduces the total biomass of the stocks [29]. The reasoning behind this effect is that fishing activity affects prey availability through changes in the substrate. In the remaining part of this section is assumed that fishing has negative consequences on fish growth and that implementing an MPA could potentially restore the habitat and increase the fish stock growth towards former levels. In this case

[4] For $\gamma>1-\varepsilon$ there is of course no asymptote because of the limit $m=1$. In this case there is an upper limit to the effort level, found by substituting $m=1$ in (7).

the intrinsic growth rate in the MPA becomes a function of the reserve size; $\tilde{r}(m)$, with $\tilde{r}'(m)>0$.

The intuition behind the reserve size based growth rate is that an ecosystem supplies a number of different functions which are spatially distributed, for instance spawning and nursery grounds, juvenile and feeding areas, as well as hiding places. The larger the un-fished areas, the more of these functions become protected, and the more they supply growth related services that increase the intrinsic growth. Thus, before fishing starts on a virgin stock, the intrinsic growth rate is at its high virgin level r. When fishing is introduced, habitat deteriorates, reducing the intrinsic growth rate to $r(0)$. The implementation of an MPA allows habitat to recover and thus the intrinsic growth rate of this part of the stock's distribution area increases towards its virgin maximum. The fact that effort does not affect the intrinsic growth rate directly – $r(0)$ being a parameter – can be explained at least in two ways [30]. First, even though the same areas and habitats repeatedly are fished upon, the destructive habitat effects may occur upon the first fishing contact. Increased effort in the same area does therefore not decrease habitat any further. Second, $r(0)$ is the reduced intrinsic growth rate when the open-access fishery has reached its bioeconomic equilibrium. In this case the habitat may only be reduced further if economic and technical parameters change.

The habitat destruction with change from r to $r(0)$, and the restoration capacity of an MPA, give us a new Eq. (2) with $\tilde{r}(m)$ and $\tilde{\gamma}(m)$, while Eq. (3) remains unchanged,

$$\tilde{\gamma}(m)=\frac{\sigma}{\tilde{r}(m)}>\gamma.$$

Applying this gives a new precautionary effort level:

$$\tilde{E}_\varepsilon=1-\varepsilon+\frac{m(1-\varepsilon)+(\gamma-\tilde{\gamma}(m))}{\tilde{\gamma}(m)/m(1-\varepsilon)-1}. \tag{7a}$$

when there is a negative habitat effect of fishing, the precautionary effort curves in Fig. 1 shift to the right, though still emanating at $\tilde{E}_\varepsilon=1-\varepsilon$, since $\tilde{E}_\varepsilon$ is now smaller than E_ε and with an asymptote at $m=\tilde{\gamma}(m)/(1-\varepsilon)$, which also shifts to the right. From this, comparing (7a) to (7), it can be seen that the *habitat effect* of fishing implies that the upper limit to effort, to assure a precautionary stock level, is reduced for any MPA size, i.e. due to the habitat effect, the stock can sustain a lower effort level before it is reduced to it's critical level ε, but this effort level increases with the MPA size, as for the curves in Fig. 1.

3.2. Food security and sustainable yield

One of the possible objectives of fisheries management, though usually not favored by economists, is maximizing sustainable yield in order to secure enough protein for people. In a single species context this implies securing maximum sustainable yield (*MSY*). Can this be achieved with an MPA in combination with an outside open-access harvest zone? For given parameter values the answer is yes in the case post-MPA growth equals pre-MPA growth as described in Eqs. (3) and (4).[5] This is illustrated in Fig. 2 where each of the two curves show for a given value of γ the combined reserve size, vertically, and the pre-MPA open-access stock level c, horizontally, necessary to achieve *MSY*.

Note some characteristics of the two curves in Fig. 2. First, only in the case that the resource is biologically overused from open-access harvesting, $c<0.50$, will the establishment of a permanent MPA succeed in realizing *MSY*. Both curves emanate at $c=0.50$ on the horizontal axis, i.e. at the *MSY* stock level. Second, only the curve for $\gamma=0.30$ intersects the vertical axis, implying that the MPA restricted open-access fishery can realize *MSY* even for very low levels of c, provided the MPA size is close to 0.60. Third, in the case of a higher γ, $\gamma=0.70$ in Fig. 2, no MPA size is large enough to realize *MSY* if c is low, $c<c_{min}$. If the stock has been fished down below c_{min}, in Fig. 2 equal to 0.15, a reserve will contribute to increased total stock and to increased harvest, but not enough to realize *MSY*. This is due to the relative migration rate γ, indicating that the migration of fish from the reserve to the harvest zone is too fast compared to the intrinsic growth needed to build up the stock to the *MSY* level (recall $\gamma=\sigma/r$). In fact it can be shown that this occurs when $\gamma>0.50$ since the intersection of the possibility curves with the vertical axis is at $m^*=2\gamma$ in Fig. 2 [15]. Fourth, an MPA may contribute to achieve *MSY* even if γ is higher than 0.50 as long as $c_{min}<c<c_{msy}$, i.e. when on the curve connecting c_{min} at $m=1$ and $c=0.50$ at $m=0$. To summarize, Fig. 2 demonstrates how MPA size must be chosen to realize *MSY* for different combinations of migration, intrinsic growth and pre-reserve stock size – the latter determined by harvest efficiency, price of fish and cost of effort.

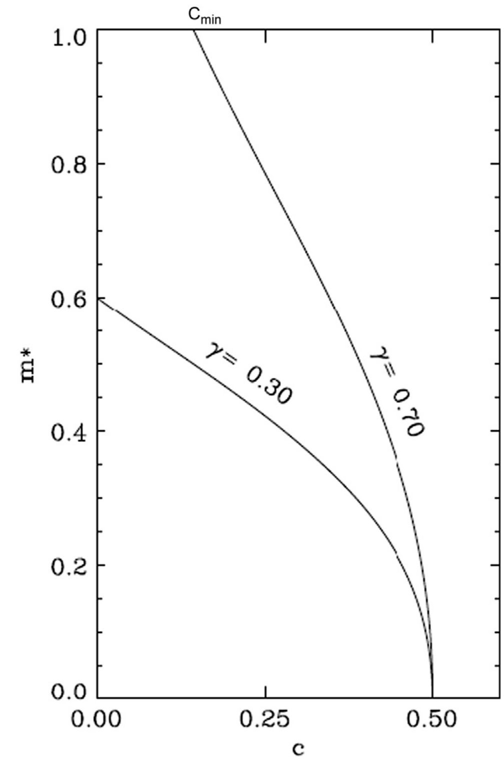

Fig. 2. Reserve size m^* that can realize maximum sustainable yield (*MSY*) depends on the pre-MPA open access stock level, c. For $\gamma<1/2$ there exists a reserve size for all $c<1/2$ that can realize MSY in the outside open access fishery. If the relative migration rate, γ, is somewhat higher ($\gamma<1/2$) a reserve can not realize MSY for low levels of c ($c_{min}=(1/2)-(\gamma/4)$).

3.3. Employment

For those who espouse a welfare approach to fisheries management, fisheries are seen as important labor market buffers in for instance poor countries, while for those taking the wealth approach, effort needs to be restricted in order for resource rent to be generated. Independent of approach taken, to know how effort and catch change when an MPA is implemented, is important. In fisheries, employment is both output and input related; total employment in the sector depends both on effort used in capture and on catch landed for processing, which may be more or less labor intensive. In the previous section the possibility of designing an MPA to maximize harvest was discussed and it is

[5] For the proof see [15].

likely that post-harvest employment in processing and distribution of fish increases with harvest. This section follows up on effort and harvest related employment by analyzing how equilibrium effort will change as a consequence of the introduction of an MPA. Effort change also means change in employment needed for the operation and maintenance of effort. Fishing effort is a composite concept, designed for use in bioeconomic models where it bridges the gap between humans' fishing activities and nature's fish stocks through fishing mortality. In actual fisheries the composition of effort varies, but with capital and labor as core inputs, in addition to other variables such as fuel, gear, bait and ice. Empirical studies have demonstrated that labor increases with effort, proportionally or at a decreasing rate (see e.g. [31–33]). In the following, by assumption, there are only quantitative changes in effort, no qualitative changes in the input mix per unit of effort.

With logistic growth such as in (1), *MSY* can be achieved if $S=1/2$. Equilibrium effort will then be $E^{msy}=1/2$ and harvest $Y=r/4=MSY$, recalling the Schaefer harvest function $Y=rE^{msy}S$ with E scaled such that the catchability coefficient equals r. To find the effort needed to secure *MSY* when there is an MPA, equate *MSY* to $rE^{msy}_{mpa}S_2$ and solve for E^{msy}_{mpa}. This yields $E^{msy}_{mpa}=1/(4c(1-m^*(c)))$ and implies that $E^{msy}_{mpa}-E^{msy}>0$ for $c<1/2$ and that the difference increases with decreasing values of c and increasing values of m, since m^* is monotonically decreasing in c (see Fig. 2). Recall that $c<1/2$ is a requirement for being able to generate *MSY* through the use of an MPA and open access in the HZ. Also recall that the values of c (below 1/2) and γ jointly determine whether *MSY* is achievable or not, and, given achievability, the size of the required reserve (m). To summarize, for certain combinations of γ and c, discussed above, an MPA and open access harvesting in HZ may realize *MSY* through increased effort, thus increasing employment in both fish processing and harvesting.

For harvest levels other than *MSY* it is necessary to limit the analysis to numerical simulations. Fig. 3 shows equilibrium harvest as a function of effort in the no MPA case and in the case of a reserve, when $m=0.25$, for two different values of γ.

As can be seen from Fig. 3, the equilibrium yield curves are skewed to the right in the case of an MPA, and the higher the value of γ, the more to the right the curve will be situated. The point where yield is zero for $E>0$ corresponds to E_ε with $\varepsilon=0$ (Eq. (7a)). It is also seen that to obtain a given yield, higher effort is required in the case of an MPA than in the pure open access case. The reason for the skewing to the right as a consequence of an MPA may be that when effort is low, there is not really a need for an MPA to protect the stock and the MPA is just a restriction without benefits. As effort becomes higher the protective benefits of the MPA ensures that total stock level is higher than in the pure open access case, and the migration results in spillover that secures a higher yield.

Fig. 4 displays open access equilibrium effort as a function of reserve size m.

With respect to employment, it is concluded below that for the cases when the MPA can realize *MSY*, both fishing and post-harvest employment increases with MPA size up to the *MSY* reserve size. Panel A in Fig. 4 shows how effort changes with m in the case of a heavily overfished stock ($c=0.15$) and panel B for a slightly overfished stock ($c=0.45$). At $m=0$ effort is equal to the pure open access case, $E=1-c$. It can be seen that the value of c determines the maximum of E, in fact this is the maximum sustainable yield effort $E^{msy}_{mpa}=1/4c$, whereas the value of γ influences the location of the maximum. The reason for this is that the speed at which the fish migrate influences the stock size within the MPA, and for slow moving fish there will be a sufficiently large stock within the MPA to provide high spillover levels at low MPA sizes. As the MPA increases in size, the low speed of migration ensures that more of the fish is retained within the reserve, thereby reducing the spillover effect. For species with a high γ, the stock build-up within the reserve is too low to provide high levels of spillover when the MPA is small. As the MPA increases, so does the stock level and the high speed of migration ensures that large spillover effects are generated even at large MPA sizes. With respect to employment, it has been demonstrated that for the cases when the MPA can realize *MSY*, both fishing and processing employment increase with MPA size up to the *MSY* reserve. However, further increase will reduce both effort and processing employment.

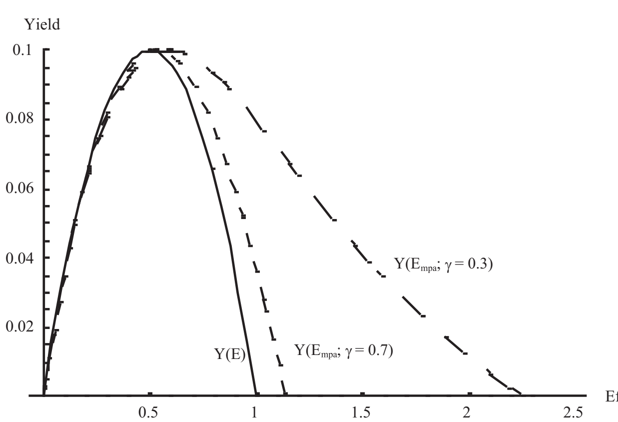

Fig. 3. Equilibrium yield as a function of effort. Solid line represents the no MPA case and broken lines the case of an MPA being 25% of the distribution area.

3.4. Consumer surplus

With constant price of harvest and cost of effort no resource rent, consumer surplus (CS) and producer surplus (PS), are generated in

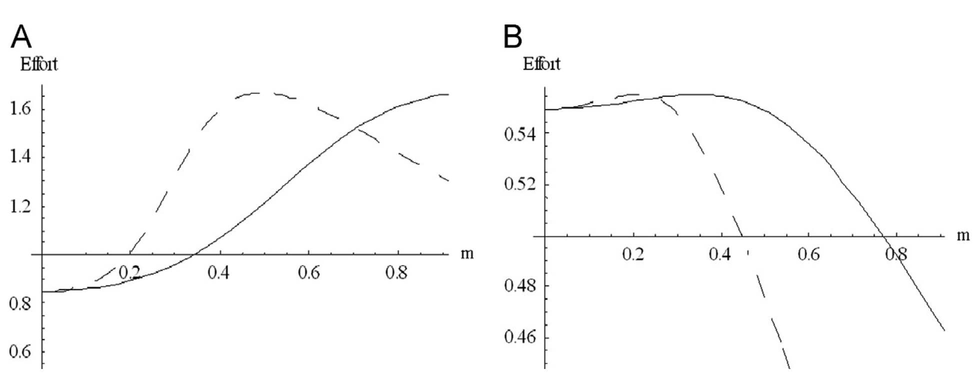

Fig. 4. Open access equilibrium effort as a function of reserve size when $c=0.15$ (A) and when $c=0.45$ (B). Solid and broken lines represent cases where $\gamma=0.7$ and $\gamma=0.3$, respectively. Note the differences in the vertical placing of the horizontal axes and the scales along the vertical axes.

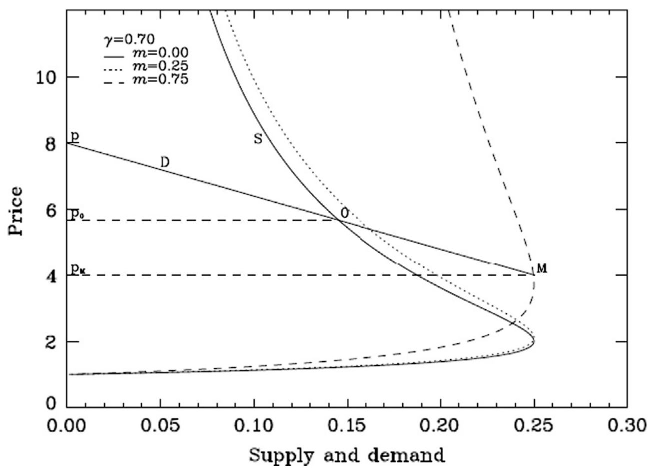

Fig. 5. Backward bending open-access supply curves and consumer surplus (CS). The triangle p_oOp is the CS for overall open-access and the triangle p_MMp is the CS for a nature reserve tuned to give nearly MSY, when allowing open-access in the harvest zone.

the analyses above. Then, from an economic point of view, why bother with establishing MPAs if no economic rent is generated? There are at least two answers to this. First, actual fishing fleets often display heterogeneous vessels and costs – implying intra-marginal rent in open-access fisheries [33] – to be discussed below. Second, actual fish markets often display downward sloping demand and the possibilities of CS. This will now be discussed. The increased harvest following the creation of an MPA (see above) combined with a downward sloping demand curve allows for the creation of CS. Pezzey et al. [22] mention additionally, in the case of marine reserves, the possibility of a shift in demand caused by "more desirable fish" and in supply, caused by "more easily catchable fish". Now, investigate the case of consumer surplus to see how this changes the previous conclusions about zero economic rent.

Fig. 5 shows the backward bending long-run open-access supply curve as a function of the fish price, assuming all other parameters being constant, [34] and [35].[6] With a downward sloping demand curve for harvest assume that there is a unique stable equilibrium at overall open-access, with price of harvest p_o and harvest Y at O[7] (Fig. 5). With an MPA the backward bending supply curve shifts to the right and upwards. The *MSY* supply (equal to 0.25) is the same for all three curves. Demand and supply conditions in Fig. 5 have been chosen such that HZ open-access is close to realizing *MSY* for MPA size $m=0.75$. In this case, the CS equals the triangle p_mMp, which is significantly greater than the pre-MPA CS triangle p_oOp. As demonstrated above, tuning reserve size to realize *MSY*, under HZ open-access, may or may not be possible, depending on biological and economic parameters. The case of biological over-exploitation pre-MPA and open-access harvesting in the HZ post-MPA implies increased harvest as well as increased consumer surplus when demand is downward sloping. This is clearly an economic benefit to be expected from MPA creation for over-exploited resources. Consumer surplus may be of great importance for some resources, for example those harvested and used for easily perishable food at limited size local or national markets.

3.5. Producer surplus

In the above analysis it has for simplicity been assumed that vessels are homogenous. If vessels are heterogeneous, which is usually thought to be a more realistic assumption, total cost of fishing will be non-linear and the most efficient vessels will earn a super-normal profit in spite of open access [21]. This rent is often referred to as intra-marginal rent or producer surplus (PS), and a recent example for an open-access developing country fishery is demonstrated in [33]. Now the question is whether an MPA as the only policy instrument can potentially increase PS.

Open access equilibrium effort is found where average revenue *AR(E)* is equal to marginal cost *MC(E)*. With no MPA and total costs now assumed to be $C=\alpha E^2$, equilibrium open access effort and stock will be given by $E^\infty = pr/(pr+2\alpha)$ and $S^\infty = 2\alpha/(pr+2\alpha)$. As noted above the reason for choosing the well-known quadratic cost function is to let the *MC* increase in E in a simple way. The alternative $C=\alpha E^a$, with $1<a<2$ would add another parameter, a, to the expressions of E^∞ and S^∞. However, for empirical analysis this, and possibly also a constant term in the C-function should *a priory* be included, as in [33]. With an MPA, open access stock level in the harvest zone becomes $S_2^\infty = c(1-m)$, recalling that the pre-reserve open access stock level is c. Fig. 4 shows four curves for E^∞ as a function of reserve size m. Effort will increase with any reserve size if the relative migration rate γ is large and the pre-reserve stock is heavily overexploited (Fig. 4, panel A, solid line). In the other three cases shown, effort increases with reserve size up to between 0.2 and 0.5, then decreases. Actual reserves are rarely greater than 20–50% of the total resource area. Note that for panel A of Fig. 4 both curves represent a heavily overexploited resource (down to 15% of the virgin stock level), and even for the broken curve with moderate relative migration ($\gamma=0.3$) effort increases with reserve size up to about $m=0.5$. The PS will increase when effort increases. The value of the parameter α of the total cost curve is by assumption adjusted such that effort at the pre-MPA open access equilibrium is the same as in the linear cost case, hence Fig. 4 can be used to find when an MPA will increase PS. MPA sizes which result in an equilibrium effort level higher than E^∞ (the intercept), will also increase PS. Therefore it is seen that in the case of a heavily overfished stock (panel A) an MPA of almost any size will cause equilibrium effort, and hence also PS, to increase. In the case of a moderately overfished stock (panel B), it is seen that an MPA of the correct size can result only in small increases in effort, hence also only a small increase in PS, whereas too large a reserve may cause effort and PS to decrease compared to the pure open access case. Values for α are listed in Table 1.

4. Discussion

It is a well-known result in resource economics that no rent is generated under open access within the Gordon–Schaefer model with constant price of fish and homogenous effort. However, it is also known that small changes in the underlying assumptions may allow for rent generation, in particular consumer and producer surplus. This paper has discussed the possibility of such rent generation by use of an MPA with open access fishing outside. Maximizing total economic rent may of course not be the only objective for fisheries management. Therefore, within this MPA approach it is also discussed what would usually be classified as ecological objectives, namely resource conservation and restoration and maximum sustainable yield, as well as social objectives, such as employment and food security.

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[6] In the MPA case S is based on HZ open-access harvesting, which implies $S_2=(1-m)a/pr=(1-m)c$. Substituting for this S_2 into (4) gives in equilibrium

$$Y = r(S_1+(1-m)c)(1-(S_1+(1-m)c))$$

where S_1 is implicitly given by (2). Thus Y is now implicitly a function of reserve, biological and economic parameters, including price of harvest, and is shown as the S dotted and broken curves in Fig. 3.

[7] For a discussion of multiple equilibria, see [36].

For developing countries, which typically have fisheries in tropical ecosystems characterized by a high number of species and mixed fisheries, limited resources available for fisheries management and a high degree of subsistence and small scale fisheries, the management tools often used by industrialized countries are not suitable. Taxing or controlling the harvest of thousands of vessels, each catching a small amount which is sold on local markets would be very demanding. Fisheries management does not come for free and monitoring, control and enforcement are not perfect, usually resulting in some IUU fishing [37]. For actual management the efficiency and costs of different instruments should be an integral part of the policy discussion. OECD fishing countries had, in the period 1987–2007, on average a decline in fish catches of about two percent per year, whereas the other fishing nations worldwide had an annual increase of about two percent, despite the more advanced instruments of the former [38]. Due to overfishing and decline in catches in several member countries the OECD has instigated discussions and analyses to mitigate such problems [39,40]. Controlling that no one fish in a particular area (MPA) might be easier and cheaper than conventional input and output control, but it is essential to know how closing of an area will affect stocks, harvest, vessels and labor, and if there could be any economic and social benefits generated by doing so.

5. Concluding remarks

The introduction described briefly the current debate regarding the appropriate approach to fisheries management in developing countries. Those fronting the so-called welfare approach argue that open access fisheries have a value as a source of food for poor people and as a labor market buffer, while those defending the wealth approach claim that effort has to be reduced in order for rent to be generated.

This paper has shown that for heavily overfished stocks an MPA may be used to protect stocks and their habitats, to maximize harvest and to increase consumer and producer surplus. It may also cause the number of people employed in the fishery to increase, both as a consequence of increased effort and an increase in landed quantity for processing and distribution. For moderately overfished stocks the benefits are not as apparent. These findings suggest that applying MPAs as management instruments may be suitable when taking the welfare approach to fisheries management, but not when taking the wealth approach. It is however not unlikely that even if a country initially may see the welfare approach as the most sensible, a transformation towards a wealth-based management system may be desirable in the long run as the general economy improves and good institutions and systems for redistribution of wealth are developed. In this case the use of MPAs may slow the process simply because more people may be involved in the fishery than would otherwise be the case if it was left in a pure open access state. However, as demonstrated in this paper, when there are other management objectives than resource rent maximization, MPAs have a role to play to enhance resources and marine ecosystem services and to improve economic and social welfare.

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