PROTECTED AREAS FOR CONFLICT RESOLUTION AND MANAGEMENT OF RECREATIONAL AND COMMERCIAL FISHERIES

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ABSTRACT

This paper investigates interactions between recreational and commercial fisheries. It introduces the idea of a protected area for recreational fisheries, as a way to reduce conflicts between the two sectors and to preserve the natural resource. It is demonstrated that without a protected area for recreational fisheries, open access may imply that only one sector survives. A protected area can assure the operation of both sectors, even under open access. This will also enhance the aggregate fish stock and the aggregate harvest, both in open access and in the optimal management of recreational fisheries, even if commercial fisheries operate under an open access regime.

Key words: protected area for recreational fisheries, bioeconomic modeling, recreational fisheries, recreational and commercial fisheries interactions, ocean zoning.

INTRODUCTION

Like commercial fisheries, the number of participants in recreational fisheries is increasing around the world due to increases in wealth, leisure time, and tourism. In developed countries, 2.4% of the population on average participates in recreational fishing (Pitcher and Hollingworth, 2002). In developing countries (e.g. South African line fisheries), only half of one percent of the population appears to be involved in fishing as a sport (Griffiths and Lamberth, 2002). The increasing number of participants in recreational fishing has placed pressure on marine resources and lead to conflicts with commercial fisheries. There were evidences of dramatic declines in four high-profile fisheries in Canada and in fish populations in several coastal regions in the United States, attributable to recreational fisheries (Post et al., 2002; Coleman et al., 2004).

Desire to preserve resources requires more understanding of management measures in recreational fisheries and the conflicts with commercial fisheries as well. Such topics have been studied by ecological fisheries and economic scientists (Pitcher and Hollingworth, 2002). Economic literature often deals with inefficient allocation of the resources under open access and it often examines efficient allocation that maximizes the present discounted value of recreational and commercial benefits. Connell and Sutinen (1979) applied the bioeconomic model in the recreational context where angler demand is solely a function of the quantity of trips and the harvest per trip. Bishop and Samples (1980) consider the issue of the optimal harvest allocation of a fishery that is shared between commercial and recreational fisheries, by adding a recreational sector to a standard commercial fishing optimal control model. Laukkanen (2001) studied the optimal exploitation strategy for four sequential fisheries, of which one was a recreational fishery while Sumaila (2002) studied how the coexistence of sport and commercial fisheries in Namibian can be managed using the Nash equilibrium game theory.

A key question investigated in this paper is if and how zoning can mitigate recreational-commercial fisheries conflicts. Marine spatial planning and ocean zoning have been seen as a will that may create a framework facilitating both the realignment of industry incentive and the attainment of the broader goal of healthier ocean ecosystem (Eagle, Sanchirico and Barton 2008). The theory of spatial zoning focuses on the selection of a protected area and its size. We develop a bioeconomic model to address the competition and management of recreational and commercial fisheries. We study harvest strategies, focusing on the allocation of catches between these fisheries. We depart from the Bishop-Samples model because we study recreational and commercial fisheries in a standard bioeconomic model. However, we investigate the open access management regime for both sectors as a base for further discussion. A consequence of open access in the two sectors is that one of the sectors may have to close down. We introduce a protected area for the recreational fishery as a measure to solve the conflict. We will compare the aggregate stock and aggregate harvest before and after the establishment of a protected area for the recreational fishery. This comparison is useful in examining how a protected area can contribute to a fishery management objective. To the best of our knowledge, this protected area modeling of recreational–commercial fisheries is novel.

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Whether or not a protected area for recreational fisheries is established, the commercial fishery, by assumption, operates under open access conditions. Several investigations regarding the open access commercial fishery with the presence of a no-take marine reserve have been conducted (see e.g. Pezzey et al. (2000); Sanchirico and Wilen (2001); Ngoc (2010); Flaaten and Mjolhus (2010)). The open access regime is chosen in this literature to examine whether and under what conditions a marine reserve can create social and ecological benefits and work as a management tool, instead of applying conventional tools.

The paper is organized as follows. In Section 2, the basic bioeconomic model is presented, when the recreational fishery is without a protected area. In Section 3, we analyze the interaction between recreational and commercial fisheries when the protected area is established for the recreational fishery. In Section 4, we compare different management regimes, the aggregate stock, and aggregate harvest, before and after the creation of a protected area. Finally, in Section 5, we conclude the paper with a discussion of its findings.

THE BASIC MODEL

We will consider first the characteristics of a basic fishery model without the protected area. We assume that a fish stock is located in an area of unit size and that the natural growth rate for the fish population exhibits logistic growth pattern, thus

$$G(S) = rS(1-S), \qquad (1)$$

where S is the size of fish population, r is the intrinsic growth rate. It should be noted that carrying capacity is normalized to one and $G(S)$ is a strictly concave function. The rate of change of the stock with the presence of the harvests is given by

$$\frac{dS}{dt} = rS(1-S) - g - h, \qquad (2)$$

g and h are the harvests from recreational and commercial fisheries respectively.

Following Bishop and Samples (1980), we assume that $v(S)$ is the gross benefit per unit of fish caught by recreational anglers, $v'(S) > 0$, and $j(S)$ is the average cost of catching fish in the recreational fishery, $j'(S) < 0$. Thus $R(S) = v(S) - j(S)$ is the net benefit per unit of fish caught recreationally, where $R'(S) > 0$. The demand for recreational catch is perfectly elastic with respect to g. For the commercial fishery, let p be the price per unit of commercial catch, where demand is assumed to be perfectly elastic and $c(S)$ be the cost of catching per unit of fish caught $c'(S) < 0$. Hence $C(S) = p - c(S)$ is the rent, or benefit per unit, of fish caught commercially. Note that demands for recreational and commercial catches are perfectly elastic and effort costs are linear in effort; thus, there is no consumer surplus or producer surplus generated in our analysis.

Open access equilibrium

Open access, bioeconomic equilibrium occurs when there is simultaneously economic and biological equilibrium, with the aggregate harvest equaling the fish growth. The open access bioeconomic equilibrium of a joint recreational and commercial fishery is implicitly defined by

$$R(S)g = 0, \qquad (3)$$

$$C(S)h = 0, \qquad (4)$$

$$\frac{dS}{dt} = rS(1-S) - g - h = 0. \qquad (5)$$

For the purpose of further analysis, we assume the net benefit functions for recreational and commercial fisheries as $R(S) = aS - \frac{c_R}{S}$ and $C(S) = p - \frac{c_C}{S}$, respectively. a, c_R, p and c_C are parameters. The open access condition for the fisheries can be simply obtained by setting the net benefit functions of two sectors equal to zero. If the fishery is solely exploited by the recreational or the commercial sector. The open access stock levels for recreational and commercial fisheries are $S_R^\infty = \sqrt{\frac{c_R}{a}}$ and $S_C^\infty = \frac{c_C}{p}$, respectively. Anglers or fishermen may continue to fish until the stock level approaches the open access stock level for each fishery.

By contrast, if the population is exploited by the both sectors, the difference in cost efficiency may lead to interactions between them. One significant question arisen here is: what is the equilibrium point in this joint fishery? There are three possibilities.

If the two sectors are equally cost efficient, $S^{\infty} = \frac{c_C}{p} = \sqrt{\frac{c_R}{a}}$, (6)

it is immediately clear that the general open access stock equilibrium of a joint commercial and recreational fishery can be achieved. At this stock level, both sectors coexist in the fishery. The aggregate equilibrium harvest includes the harvests of both sectors. Equation (6) is a strict constraint for a general equilibrium. A change of one of the parameters can violate this constraint and it is possible that either the recreational anglers or the commercial fishermen may have to leave the fishery.

In the case $S^{\infty} = \sqrt{\frac{c_R}{a}} < \frac{c_C}{p}$, the recreational fishery is more advanced than the commercial fishery, in the sense that its combined technology, costs, and market values put more pressure on the stock than that of the commercial fishery. The commercial fishermen will have to leave the fishery. The fishery is only exploited by recreational anglers so the equilibrium harvest just includes the recreational harvest. In our model, for simplicity the vessels are assumed to be homogeneous. However, in actual cases vessels vary with respect to technical and economic characteristics such as size, engine power, gear type and cost structure. Heterogeneous fishing fleets may create economic surplus. In such cases, some commercial fishermen may still be able to participate in the fishery since they can earn intra-marginal rent. Thus coexistence between commercial fishermen and recreational anglers can well be expected in actual fisheries.

Now suppose that $S^{\infty} = \frac{c_C}{p} < \sqrt{\frac{c_R}{a}}$. The net benefit from the harvest of recreational fisheries is negative. Thus, in contrast with previous case, the recreational anglers will leave the fishery. If the vessels are heterogeneous, the intra-marginal rent may exist and some recreational anglers may participate in the fishery. However, for the long run, the fishery will be solely exploited by commercial fishermen so the equilibrium harvest for the fishery only includes the harvest from commercial fisheries.

There are two cases where the open access combination of recreational and commercial fishing does not assure the operation of both sectors. As the commercial fishery, by assumption, always operates under open access, we will discuss appropriate management measures for a recreational fishery to achieve an equilibrium with the harvest in both sectors.

Management strategies for a recreational fishery with competition from an open access commercial fishery

As discussed above, open access for both fisheries' sectors gives rise to three cases. In the first case, due to equilibrium open access stock levels of two sectors are equal to each other, the operation strategy would be to allow open-access regimes in both fisheries. Here, we will only examine the last two cases.

i) The recreational fishery is more economically efficient than commercial fishery, $S_R^{\infty} < S_C^{\infty}$

Maybe we should not expect to find it in actual fisheries. Since, if the recreational fishery were more efficient than the commercial fishery, then rational commercial fishermen would change and use the same fishing technology as the recreational anglers. Nevertheless, let us assume that the manager's problem is whether to choose a management plan for the recreational fishery, with the constraint that there exists an actual or possible open-access commercial fishery with the equilibrium stock level $S_C^{\infty} = \frac{c_C}{p}$.

We assume that the manager uses the optimal strategy, which follows from maximizing the present value of the recreational fishery benefit. In the case of an autonomous model with harvest that is linear in effort, there exists a long run optimal steady state and the optimal path towards steady state is the most rapid approach (Spence and Starrett 1975). Thus, we proceed by focusing on the optimal steady state. The objective function is then given by

$$max\,PV(g) = \int_0^\infty e^{-\delta t} R(S) g dt \tag{7}$$

subject to

$$\frac{dS}{dt} = G(S) - g - h^\infty, \tag{8}$$

with $S(0)$ given and $0 \le g \le g_{max}$ where g_{max} is a constraint on the harvest capacity of the recreational sector and δ is social discount rate.

The present value Hamiltonian resulting from this maximization problem can be expressed as follows

$$H = e^{-\delta t} R(S) g + \lambda(t)\left[G(S) - g - h^\infty\right], \tag{9}$$

where $\lambda(t)$ is the shadow price of the population. It is also known as the adjoint variable.

Since the Hamiltonian is linear in the control variable g, the switching function will determine the optimal level of catch for the recreational anglers in the fishery. The switching function is defined by $\sigma(t) = e^{-\delta t} R(S) - \lambda(t)$. Thus, if $\sigma(t) > 0$, $g = g_{max}$ and if $\sigma(t) < 0$, $g = 0$. In the case $\sigma(t) = 0$, the recreational harvest is on the singular path. Clark and Munro (1975) show that the vanishing of the switching function implies a singular solution for S that can be stated by the following equation

$$G'\left(S_R^*\right) + \frac{R'\left(S_R^*\right)\left(G\left(S_R^*\right) - h^\infty\right)}{R\left(S_R^*\right)} = \delta \cdot \tag{10}$$

S_R^* is the optimal level of the fish stock if the recreational fishery is optimal along the time path.

Equation (10) is known as the golden rule in the fishery. It states that the optimal stock level for the recreational fishery is the level that maximizes the benefit. The presence of an open access commercial fishery impacts on the fish stock and, naturally, it impacts on the management strategy for the recreational fishery. The optimal harvest policy for recreational fisheries will depend on the open access stock level for commercial fisheries. Thus, the optimal approach for the recreational fishery to the general equilibrium can be stated as

$$g^*(t) = \begin{cases} g_{\max} & \\ G\left(S_R^*\right) - h^\infty & \text{whenever} \\ 0 & \end{cases} \quad \begin{matrix} c_c / p > S_R^* \\ c_C / p = S_R^* \\ c_C / p < S_R^* \end{matrix}. \tag{11}$$

With $\frac{c_C}{p} > S_R^*$, the harvest rate g_{max} will drive the stock $S = \frac{c_C}{p}$ toward S_R^* and the commercial fishermen would have to exit the fishery. This result contradicts the assumption that the commercial fishery may operate under open access conditions. On the other hand, the case $\frac{c_C}{p} < S_R^*$ implies that there is no participation of recreational anglers in the fishery. Only at the steady state equilibrium of $S_R^* = \frac{c_C}{p}$ may the two sectors coexist in the fishery. The commercial fishery operates under its open access condition while the recreational fishery operates under some form of management restriction that allows $g^* = G(S_R^*) - h^\infty$. Note that this implies a need for a mechanism to share the total catch between the two fisheries.

(ii) The recreational fishery is less economically efficient than the commercial fishery, $S_C^\infty < S_R^\infty$

In this case, the recreational anglers will not participate in the fishery since the stock level at open access is too low. Under this scheme, the spatial zoning approach is an appropriate management tool that can secure the operation of recreational fisheries since it provides the security for recreational fisheries through exclusion of commercial fisheries. Also, in relation to case (i) $S_C^\infty > S_R^\infty$, spatial zoning can be used for a similar purpose – to allow the two fisheries to coexist.

PROTECTED AREAS FOR RECREATIONAL FISHERIES

There are several types of protected areas, with different levels of protection. The managers can divide the ocean into a number of different zones and areas and then decide what use of ocean could be made in each zone. Bohnsack (1993) argues that creation of a protected area reduces conflicts between user groups by physically separating the interests of fisheries and non-fisheries. In this paper, we introduce a protected area for the recreational fishery as a measure to reduce conflicts between recreational and commercial fisheries by separating the fishing grounds into two. There are some examples of zoning mechanisms like this in Australia. The Great Barrier Reef Marine Park has some zones that allow recreational use only. In New South Wales, 30 Recreational Fishing Havens have been established utilizing fisheries management closures that exclude commercial fishing (Rayns et al., 2006). In this section, we will discuss how a protected area for recreational fisheries under ocean zoning plan may assist in resource allocation for recreational anglers, and how the aggregate stock and harvests are affected by a protected area.

Most bioeconomic models of protected areas are developed to examine the effects of protected areas (normally no-take reserves) on commercial fisheries (see e.g., Hannesson (1998); Sumaila (1998); Flaaten and Mjølhus, 2010). Our model is designed to analyze the impact on recreational and commercial fishing of a protected area for recreational fisheries. In our case, a protected area for recreational fisheries segregates the fishing activities of two sectors in two different fishing grounds. The commercial fishermen only fish outside the protected area.

The creation of a protected area for a recreational fishery leads to a fraction m of the total area of unit size that must be set aside for the recreational fishery; and $1-m$ is the area for the commercial fishery. Since the recreational sector operates inside the protected area and the commercial sector operates in the outer area, we define S_{R_m} and S_{C_m} as population stocks and $G(S_{R_m})$and $G(S_{C_m})$ as the natural growth rates of the population inside and outside the protected area which are assumed as $G(S_{R_m}) = rS_{R_m}\left(1-\frac{S_{R_m}}{m}\right)$ and $G(S_{C_m}) = rS_{C_m}\left(1-\frac{S_{C_m}}{1-m}\right)$.

Assuming that the migration between the protected area and the outside area occurs, the rates of change in biomass, inside and outside the protected area, are modeled as follows

$$\frac{dS_{R_m}}{dt} = G(S_{R_m}) - z\left(\frac{S_{R_m}}{m} - \frac{S_{C_m}}{1-m}\right) - g_m, \tag{12}$$

$$\frac{dS_{C_m}}{dt} = G(S_{C_m}) + z\left(\frac{S_{R_m}}{m} - \frac{S_{C_m}}{1-m}\right) - h_m, \tag{13}$$

where z is the migration rate, g_m is the recreational harvest and h_m is the commercial harvest after the protected area is established. These two dynamic equations will be used to analyze firstly, the open-access equilibrium, then the optimal management of the recreational fishery within this reserve framework.

Open access equilibrium

Although the participants of the two sectors are exploited in the different patches and in the different fish stocks, the question of how to allocate the total harvest and the resource between recreational fisheries and commercial fisheries is of interest. There are some key reasons for this. First, there is a biological linkage between the two patches due to the dispersal of fish between them; so the rate of change of the fish stock will involve the growth of the fish stock and the dispersal process. Second, the way to allocate the resource will have consequences on the sustainability of the stock, the amount of market value from the resource, and the social and environmental objectives of the fisheries (Sumaila, 2002).

The benefits for recreational anglers and commercial fishermen are defined as $R(S_{R_m})g_m$ and $C(S_{C_m})h_m$, respectively. The open access dissipates the benefits (rents) of the two sectors. The benefit functions are modified as $R\left(\frac{S_{R_m}}{m}\right) = a\frac{S_{R_m}}{m} - \frac{c_R}{S_{R_m}}m$ and $C\left(\frac{S_{C_m}}{1-m}\right) = p - \frac{c_C}{S_{C_m}}(1-m)$, respectively.

The open access equilibrium stocks in the two patches can be defined by setting the above net benefits equal to zero

$$S_{R_m}^{\infty} = m\sqrt{\frac{c_R}{a}}, \tag{14}$$

$$S_{C_m}^{\infty} = (1-m)\frac{c_C}{p}. \tag{15}$$

Equation (14) and equation (15) show that an expansion of the protected area directly affects the open access equilibrium sub-stock. It increases the open access stock inside the protected area but it decreases the equilibrium stock in the outer area. Only when $m = \frac{c_C}{p} / \left(\sqrt{\frac{c_R}{a}} + \frac{c_C}{p} \right)$, the open access equilibrium stock in both patches will equal each other. So if $m = \frac{c_C}{p} / \left(\sqrt{\frac{c_R}{a}} + \frac{c_C}{p} \right)$, then $S_{R_m}^{\infty} < S_{C_m}^{\infty}$ and if $m = \frac{c_C}{p} / \left(\sqrt{\frac{c_R}{a}} + \frac{c_C}{p} \right)$, then $S_{R_m}^{\infty} > S_{C_m}^{\infty}$. m can be seen as a resource allocation parameter. The choice of m may impact on the stock level for recreational and commercial fishing and consequently, it will affect recreational and commercial harvests.

If we substitute the open access stocks from (14) and (15) into (12) and (13) and let them equal zero, the equilibrium harvests for recreational and commercial fisheries, which include two components, the natural growth rate, and the migration rate between two patches can be found as

$$g_m^{\infty} = r\sqrt{\frac{c_R}{a}}m\left(1-\sqrt{\frac{c_R}{a}}\right) - z\left(\sqrt{\frac{c_R}{a}} - \frac{c_C}{p}\right), \tag{16}$$

$$h_m^{\infty} = r\frac{c_C}{p}(1-m)\left(1-\frac{c_C}{p}\right) + z\left(\sqrt{\frac{c_R}{a}} - \frac{c_C}{p}\right). \tag{17}$$

where g_m^{∞} and h_m^{∞} are the equilibrium harvests for recreational and commercial fisheries with the creation of the protected area under open access condition, respectively. The aggregate harvest can be obtained by adding (16) and (17) and it equals combining natural growth rate of the fish stock inside and outside the protected area. The aggregate harvest therefore gives the relationship between the fish abundance inside and outside the protected area and the harvests there.

There is an interaction between the two sectors due to the dispersal process, which may affect the harvest of each sector. The dispersal process can be seen as a spatial externality between the two sectors. Fishing activities, inside and outside the protected area, reduces stock density. The relative density of the population will determine the dispersal between the two patches. Thus, even when fishing in different fishing grounds, the activity of commercial fishermen may affect that of recreational anglers and vice versa. If the biological parameters r and z are assumed as given, then both the recreational and commercial harvests become a function of economic parameters c_C / p and $\sqrt{c_R / a}$. An increase in the cost of commercial fishing will make the stock outside the protected area increase. This may help the recreational harvest increase due to the benefit from the dispersal from the outer area into the protected area.

From (16) and (17), it can be seen that both sectors may coexist when the protected area is created even if they operate under open access condition and if they are different in cost efficiency. However, it should be noted that the open-access steady state harvest from one of two fisheries may still be zero. When the growth rate in the protected area is equal to, or less than, the emigration from the protected area to the outer area, the recreational fishing must cease. When the growth rate of the outer area is equal to, or less than, emigration from the outer area to the protected area, commercial fishing must cease. This makes sense, as the migration exceeding the natural growth seems unable to sustain the ecological equilibrium with positive stock within each patch.

The commercial and recreational fisheries, under open access, imply that the establishment of protected areas, with an open access regime for commercial fishing outside and especially recreational fishing inside, still result in inefficiencies. The fishermen and the anglers continue to increase their efforts until their benefit equals zero. Further, because of the dispersal between the two patches, the aggregate stock will be fished down. It is assumed that $S_{R_m}^{\infty}$ is open access stock inside the protected area that makes the net benefit of anglers equal to zero. A level of $S_{R_m} > S_{R_m}^{\infty}$ will make the net benefit for recreational fisheries positive, so it will attract more anglers entering the fisheries and make the stock decrease. At the high level of S_{R_m}, the dispersal of fish from the protected area to the fishing ground also increases. This may lead to the equilibrium catch of commercial fishermen, h_m^{∞} increasing and therefore, more fishermen will enter the fisheries and ultimately, may fish down the stock.

Optimal management of the recreational fisheries and open access for the commercial fisheries

Now we assume that the recreational fishery is managed to maximize the resource rent of this fishery. The equilibrium stock outside the protected area reads as $S_{C_m}^{\infty} = \frac{c_C}{p}(1-m)$. To formalize the objective function of the manager we write formally

$$max\, PV(g_m) = \int_0^{\infty} e^{-\delta t} R(S_{R_m}) g_m dt \qquad (18)$$

subject to

$$\frac{dS_{R_m}}{dt} = G(S_{R_m}) - z\left(\frac{S_{R_m}}{m} - \frac{c_C}{p}\right) - g_m, \qquad (19)$$

The Hamiltonian for this problem is

$$H = e^{-\delta t} R(S_{R_m}) g_m + \lambda\left[G(S_{R_m}) - z\left(\frac{S_{R_m}}{m} - \frac{c_C}{p}\right) - g_m\right], \qquad (20)$$

with $S_{R_m}(0)$ given and g_m as the control variable, where $0 \le g \le g_m^{max}$. S_{R_m} is state variable; λ is adjoint variable, or shadow value of the population stock S_{R_m} inside the protected area; and δ is social discounted rate.

The adjoint equation in this case is

$$-\dot{\lambda} = \frac{\partial H}{\partial S_{R_m}} = e^{-\delta t} R'(S_{R_m}) g_m + \lambda\left[G'(S_{R_m}) - \frac{z}{m}\right]. \qquad (21)$$

As previously, a singular solution only arises when the coefficient of g_m (the switching function, $\sigma_m(t) = e^{-\delta t} R(S_{R_m}) - \lambda(t)$) is zero. The optimal equilibrium stock if the recreational fishery is optimal along the time path is found from evaluating singular path and adjoint equation as follows

$$\left[G'(S_{R_m}) - \frac{z}{m}\right] + \frac{R'(S_{R_m}^*)}{R(S_{R_m}^*)}\left[G(S_{R_m}^*) - z\left(\frac{S_{R_m}^*}{m} - \frac{c_C}{p}\right)\right] = \delta \qquad (22)$$

where $R'(S_{R_m})$ and $G'(S_{R_m})$ are representative of partial derivatives of the net benefit function and the growth function for the protected area, with respect to the stock population.

The golden rule (22) can be explained the following way. The first component on the left-hand side, $\left[G'(S_{R_m}) - \frac{z}{m}\right]$, is the marginal product of the optimal stock size $S_{R_m}^*$. The second component, $\frac{R'(S_{R_m}^*)}{R(S_{R_m}^*)}\left[G(S_{R_m}^*) - z\left(\frac{S_{R_m}^*}{m} - \frac{c_C}{p}\right)\right]$, is the marginal stock effect emanating from the recreational fisheries. Therefore, (22) states that the optimal stock for recreational fisheries, $S_{R_m}^*$, is one at which the sum of the marginal product of the stock and the marginal stock effect equals the social rate of discount. Clark and Munro (1975) called this sum the own rate of interest of the stock. In this case, both the marginal productivity of the stock and the growth term of the marginal stock effect are adjusted for migration. The golden rule (22) equalizes the own rate of interest of the stock and the social rate of discount.

Equation (23) may be rewritten as

$$\left[G'\left(S^*_{R_m}\right)-\frac{z}{m}\right]R\left(S^*_{R_m}\right)+R'\left(R^*_{R_m}\right)\left[G\left(S_{R_m}\right)-z\left(\frac{S_{R_m}}{m}-\frac{c_C}{p}\right)\right]=\delta R\left(S^*_{R_m}\right)\cdot \tag{23}$$

The left-hand side of (23) is the present value of the marginal sustainable benefit afforded by the marginal increment to the stock. Also, it can be interpreted as the marginal user cost – the cost of capturing the marginal increment of fish. The right-hand side is the marginal benefit from recreational fishing. Hence, the optimal fish stock $S^*_{R_m}$ is defined by equalizing the present value of the marginal user cost and the marginal benefit of harvesting.

Without the presence of protected area, the optimal strategy for recreational fisheries as we study in the previous section shows that at the steady state, $G\left(S^*_R\right)$ is allocated to recreational fisheries as a rate of g^* and to commercial fisheries at a rate of h^∞ such that the net benefit of recreational fisheries equals $e^{-\delta t}\lambda(t)$ and the net benefit of commercial fisheries equals zero. The conflict between two sectors still exists. One of two sectors may be excludes if the level of fish stock falls below the level that can help them operate under their own management regime.

The creation of protected area for recreational fisheries helps to segregate the areas for recreational and commercial fishing. Thus $G\left(S^*_{R_m}\right)$ is only allocated for recreational fisheries and the activity of the recreational fisheries is assured. It is the same for commercial fisheries. The commercial harvest is assured by the natural growth rate $G\left(S_{C_m}\right)$ outside the protected area. The interaction between two sectors is only due to the dispersal process which depends on the density of the fish stock between the two parches.

The net benefit of recreational fisheries so far, has been studied as a function of economic parameters and the stock level inside the protected area. Let us investigate, in this case, how the net benefit of recreational fisheries affected by the fish stock inside and outside the protected area and by other relevant factors. The benefit from the recreational fisheries solved from (22) is given by

$$R\left(S^*_{R_m}\right)=R'\left(S^*_{R_m}\right)\frac{G\left(S^*_{R_m}\right)-z\left(\frac{S^*_{R_m}}{m}-\frac{c_C}{p}\right)}{\delta-G'\left(S^*_{R_m}\right)+\frac{z}{m}}. \tag{24}$$

As opposed to the open access solution that drives the stock to the zero net benefit level. Optimal management solution requires a reduction of harvest from recreational fisheries to where the benefit function satisfies (24). The net benefit of recreational fisheries is a function of cost–price ratio, c_C/p of commercial fisheries and other biological parameters in both areas. It increases with the cost–price ratio and the intrinsic growth rate and decreases with the migration rate. This illustrates that the benefit of recreational fisheries is dependent on the dispersal between two patches; so it will depend on relative densities and hence, cost–price ratio outside the protected area. In contrast with the case without the protected area, the benefits in this case thus, must be considered in a system of ecologically-connected patches. Removing one unit from the stock, inside or outside the protected area, will affect spillover to another patch.

From (22) we can also obtain the steady state harvest for recreational fisheries as a function of the net benefit, marginal growth rate of fish stock and discounted rate

$$g^*_m=\left(\delta-G'\left(S^*_{R_m}\right)+\frac{z}{m}\right)\frac{R\left(S^*_{R_m}\right)}{R'\left(S^*_{R_m}\right)}. \tag{25}$$

The net benefit of harvested fish is an increase function of $S^*_{R_m}$ thus, when $S^*_{R_m}$ increases, the net benefit from harvest also increases and it leads to an increase in the harvest.

COMPARISONS BEFORE AND AFTER THE CREATION OF THE PROTECTED AREA
To better understand and explain the role of the protected area for recreational fisheries, we should examine the aggregate stock and aggregate harvest increase when the protected area for recreational fishing is created. We will therefore compare the result, as regards stock size and harvest, before and after the establishment of the protected area for recreational fisheries. This comparison will show how the protected area can affect the operation of the two sectors and of the equilibrium point.

Table 1 presents the comparisons of the aggregate stock and aggregate harvests before and after creation of a protected area under open access condition for both recreational and commercial fisheries. Both recreational and commercial harvests cannot exceed the catchable stock (the natural growth rate of the fish stock). Although the equilibrium harvest equals the natural growth rate of the fish stock, the harvest of commercial fishermen is different from that of recreational anglers. The reason for this is due to the difference in cost efficiency. The difference in the cost affects the level of equilibrium fish stock and in turn, affects the harvest rate. Our fish stock in coastal oceans is more likely to be overexploited than underexploited. Consequently, a higher cost may lead to an increase in the fish stock and this in turn, makes the equilibrium harvest also increase. The magnitude of the harvest of two sectors therefore depends mostly on the magnitude of the cost exerting from their activities.

Table 1 – Comparisons of aggregate equilibrium stock and harvests before and after the creation of a protected area under open access condition for both sectors

	No protected area, open access	Protected area, open access
Scenarios	$S_C^\infty = S_R^\infty$	$S_{C_m}^\infty = S_{R_m}^\infty$
Aggregate stock	$\frac{c_C}{p} = \sqrt{\frac{c_R}{a}}$	$\frac{c_C}{p} = \sqrt{\frac{c_R}{a}}$
Aggregate harvests	$g^\infty + h^\infty = r\frac{c_C}{p}\left(1-\frac{c_C}{p}\right) = r\sqrt{\frac{c_R}{a}}\left(1-\sqrt{\frac{c_R}{a}}\right)$	$r\frac{c_C}{p}\left(1-\frac{c_C}{p}\right) = r\sqrt{\frac{c_R}{a}}\left(1-\sqrt{\frac{c_R}{a}}\right)$
Scenarios	$S_C^\infty < S_R^\infty$	$S_{C_m}^\infty < S_{R_m}^\infty$
Aggregate stock	$\frac{c_C}{p}$	$\frac{c_C}{p}(1-m) + \sqrt{\frac{c_R}{a}}m$
Aggregate harvests	$h^\infty = r\frac{c_C}{p}\left(1-\frac{c_C}{p}\right)$	$g^\infty + h^\infty = r\sqrt{\frac{c_R}{a}}m\left(1-\sqrt{\frac{c_R}{a}}\right) + r\frac{c_C}{p}(1-m)\left(1-\frac{c_C}{p}\right)$
Scenarios	$S_C^\infty > S_R^\infty$	$S_{C_m}^\infty > S_{R_m}^\infty$
Aggregate stock	$\sqrt{\frac{c_R}{a}}$	$\frac{c_C}{p}(1-m) + \sqrt{\frac{c_R}{a}}m$
Aggregate harvests	$g^\infty = r\sqrt{\frac{c_R}{a}}\left(1-\sqrt{\frac{c_R}{a}}\right)$	$g^\infty + h^\infty = r\sqrt{\frac{c_R}{a}}m\left(1-\sqrt{\frac{c_R}{a}}\right) + r\frac{c_C}{p}(1-m)\left(1-\frac{c_C}{p}\right)$

The establishment of a protected area sets up possibilities for increases in aggregate stock and aggregate harvests. Whether the stock densities inside and outside the protected area are equal or not, the aggregate stock biomass and aggregate harvests after the creation of the protected area, are at least equal to, or larger than, those prior to the creation of the protected area.

In order to be able to address effectiveness of different management regimes for recreational fisheries after the creation of protected area, we make comparisons of aggregate stock and aggregate harvests between open access and optimal management regime for recreational fisheries. Table 2 displays these comparisons.

We know from the theory that the optimal stock level $S_{R_m}^*$ will be on the range $S_{R_m}^\infty < S_{R_m}^* < S_{MEY}$, when $0 < \delta < +\infty$. Only if the future is completely discounted ($\delta = +\infty$), the optimal strategy is to exploit the stock to the level of bionomic equilibrium of the unregulated, open access fishery.

The optimal management for recreational fisheries enhances the stock inside a protected area; consequently, an aggregate stock also increases compared to open access situation. The magnitude of the aggregate harvests will depend on the magnitude of the stock level inside the protected area for recreational fisheries. When the optimal management is actually applied, the population inside a protected area for recreational fisheries increases and it begins to create a positive benefit for commercial fisheries, by dispersal flow. The harvest for open access commercial fisheries may be higher than that under open access for recreational fisheries. However, the aggregate harvests may increase or decrease. There are three possible cases:

i) If $S_{R_m}^{\infty} \le S_{R_m}^{*} \le \frac{m}{2}$, the aggregate harvest will increase, compared to the open access regime for recreational fisheries.

ii) If $S_{R_m}^{*} > S_{R_m}^{\infty} > \frac{m}{2}$, the aggregate harvest will decrease compared to the open access regime for recreational fisheries.

iii) If $S_{R_m}^{\infty} < \frac{m}{2} < S_{R_m}^{*}$, the problem is more complex. The aggregate harvest will either increase or decrease compared to the open access condition for recreational fisheries, depending on the magnitude of $S_{R_m}^{\infty}$ and $S_{R_m}^{*}$.

Table 2 – Comparisons of aggregate equilibrium stock and harvests between open access and optimal management regime for the recreational fisheries with creation of protected area

Variables	Aggregate stock	Aggregate harvests
Open access	$\frac{c_C}{p}(1-m)+\sqrt{\frac{c_R}{a}}m$	$r\sqrt{\frac{c_R}{a}}m\left(1-\sqrt{\frac{c_R}{a}}\right)+r\frac{c_C}{p}(1-m)\left(1-\frac{c_C}{p}\right)$
Optimal management	$\frac{c_C}{p}(1-m)+S_{R_m}^{*}$	$rS_{R_m}^{*}\left(1-\frac{S_{R_m}^{*}}{m}\right)+r\frac{c_C}{p}(1-m)\left(1-\frac{c_C}{p}\right)$

[1] $S_{R_m}^{*}$ is the optimal stock level for a recreational fishery defined by (22)

DISCUSSION AND CONCLUSIONS

This paper discusses a bioeconomic model of recreational and commercial fisheries and asks a pertinent question: in an open access fishery, can an area reserved for the exclusive use of one of two sectors maintain the co-existence of both recreational and commercial fisheries? Since the recreational anglers and commercial fishermen compete for the same fish, the allocation of all or part of the resource to one group, impacts on the resources available to the other group. Under open access, each sector harvests the stock to the level where the net benefit of each fishery is dissipated, so the open access solution may occur with one or both of the sectors. The participants in one of the sectors may have to leave the fishery (or they never enter it) if they are less efficient. Competition between the two sectors implies that the fishery should be managed jointly in a sustainable manner.

This paper provides the idea for the creation of a protected area for recreational fisheries, which helps to redistribute recreational and commercial fishing activities onto different locations. However, aligning the management systems used for different sectors can be challenging due to the differing objectives and mechanisms. In addition, particular management policy will affect participants' behavior differently and, in turn, will affect the aggregate stock and harvest differently. In this paper, we applied a typical analysis under different management regimes. This analysis consisted of a comparison between the harvest and stock biomass levels before and after the creation of the protected area for recreational fisheries, especially under open access conditions.

The comparison showed that the establishment of the protected area for recreational fisheries can ensure that both sectors can participate in the fisheries and resolve the conflicts amongst participants, from the two sectors. Protected areas enhance both the aggregate harvests and the aggregate stock biomass, even when both sectors still operate under open access conditions. The application of optimal management regimes for recreational fisheries can help to increase the aggregate stock. The aggregate harvests, under optimal management regimes, may be either higher than, or smaller than those under protected areas, for open access recreational fisheries, depending on the magnitude of $S_{R_m}^{\infty}$ and $S_{R_m}^{*}$ compared to $m/2$. Marine spatial planning becomes an appropriate tool because it may provide a means of avoiding and managing potential conflicts, and ensuring that the needs of different sectors are addressed in a coordinated way. Zoning has the potential to improve the efficient use of marine resources.

For simplicity, in our model the benefit of recreational fisheries is a function only depending on the fish stock. However, in reality recreational fishing is highly selective for the larger size of fish caught and the older age of the individuals. The introduction of size and age structure into the model may lead to a negative impact on the fish stock (the decrease in mean age, age diversity and abundance of legal-sized species has been observed as the outcome in some recreational fisheries (e.g. Avery and Hunt 1981; Var and Nicola 2004)). Older individuals are selected by anglers, harvest thus may lower the life span of the exploited populations. Disturbance of the population structure induced by recreational fishing can also affect the growth pattern, so that growth is usually favoured by harvest (Healey 1980; Donald and Alger 1989). As a result of concentrating exploitation on the larger individuals, the reproductive age-classes seriously declined in the exploited areas. The fish stock due to this may also decline.

The protected area for recreational fishing may help the fishery manager achieve optimal and sustainable use of the marine resource. This involves making equal use of the resource, considering the commercial fisheries always operate under open access conditions. However, a natural problem that arises from this situation is that the establishment of a protected area for recreational fisheries can lead to increased opposition from commercial fishermen. This opposition occurs because commercial fishermen are more efficient, and do not like losing their important fishing grounds; how managers deal with this problem is an important factor to consider. From reality, we know that managers may impose a fee on recreational fisheries in order to obtain optimal stock level. From a regulatory perspective, they could transfer this fee to commercial fishermen as compensation for their loss of fishing ground. In addition, the dispersal of stock biomass from a protected area to an outer area is also evidence of a benefit to commercial fishermen, which could convince them to support the creation of a protected area for recreational fisheries.

Conflicts between commercial and recreational fisheries increase globally and create challenges for fisheries' managers (Aas, 2007). This is primarily because each sector fails to recognize the impacts of their own activity on the other sectors and because recreational and commercial fisheries have been traditionally managed in isolation from each other. From our research, it is clear that only when we have a better understanding of recreational fisheries and their relationship with commercial fisheries, can we formulate more effective management plans to conserve and sustain the fish resources.

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