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THE BIOECONOMICS OF A WILD ATLANTIC SALMON (*SALMO SALAR*) RECREATIONAL FISHERY

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(*Salmo salar*) recreational fishery

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Abstract.

A biomass model of a wild salmon (*Salmo salar*) river recreational fishery is formulated, and the ways in which economic and biological conditions influence harvesting, stock size, profitability, and the benefit of the anglers are studied. The demand for recreational angling is met by fishing permits supplied by profit maximizing landowners. In line with today's stylized management practice in Norway, it is assumed that the suppliers do not take into account the fact that this year's fishing effort influences next year's stock size. Both price-taking and monopolistic supply is studied. These myopic schemes are contrasted with the social planner solution. Gear regulations in the recreational fishery, but also the commercial fishery, are analysed under the various management scenarios and the paper concludes with some policy implications. One novel result is that imposing gear restrictions in the marine fishery may have the opposite stock effect of imposing restrictions in the recreational fishery.

Key words: Bioeconomic model, conflicting interests, fishery economics, management, sport fishing, stock dynamics.

JEL classification: Q22

"River fisheries are a natural resource of a very limited character, and would be rapidly exhausted, if allowed to be used by every one without restraint"
(John Stuart Mill 1848).

1. Introduction

There has not been much good news concerning the abundance of wild salmon stocks in the North Atlantic during the last few decades. Stock development has been especially disappointing in the 1990s, due to a combination of factors, such as the sea temperature, diseases, and human activity, both in the spawning streams and through the strong growth of sea farming (NASCO 2001). Norwegian rivers are the most important spawning rivers for the East Atlantic stock, and about 30% of the remaining stock spawns here. The wild salmon are harvested by commercial and recreational fisheries. The marine harvest is mainly commercial, whereas the harvest in the spawning rivers is recreational. As the wild stock began to decrease during the 1980s, the Norwegian government imposed gear restrictions to limit the commercial harvest. Drift net fishing was banned in 1989 and the fishing season of bend nets was restricted. At the same time, the fishing season in the spawning rivers was limited. However, despite all of these measures taken to rebuild the stock, the abundance of salmon seems to be only half the level experienced in the 1960s and 1970s. The same pattern is observed other places (NASCO 2001).

After drift net fishing was banned, catches by commercial fishermen and recreational anglers have been approximately equal (NOU 1999). In this paper, however, we want to focus on the recreational fishery, as it is more important from an economic perspective. The value of the marine harvest is more or less directly related to the meat value, whereas recreational fishermen typically pay for the right to fish, and the high willingness to pay implies that the payment per kilo of actually caught fish is several times the meat value (NOU 1999). Altogether, there remain about 500 streams with spawning Atlantic salmon in Norway and sport fishing is an important recreational activity. In addition, the indirect economic effects from the river fishery are of great importance to many local communities (Fiske and Aas 2001).

The aim of this paper is to analyse how biological and economic factors affect harvest rates, stock growth, the economic benefit, and the distribution of economic benefits among anglers and landowners in a representative Norwegian salmon river. A bioeconomic biomass model is formulated where the demand for fishing is given in number of days, whereas the quality of the river, approximated by average catch per fishing day, shifts demand up. On the supply side, there are a fixed number of landowners, treated as a single agent, managing the fishery under the assumption of profit maximization. Two different management regimes are studied; price-taking and monopolistic behaviour. Under both these schemes, it is assumed that the landowners do not take into account the fact that this year's fishing effort influences next year's stock size. Management is therefore myopic. These management schemes are contrasted with the social planner solution. The model is illustrated by using ecological data from the river Imsa located on the southwestern coast of Norway (Rogaland County).

There is a substantial literature on recreational fishing[1]. The present model essentially builds on the sequential harvesting model of Charles and Reed (1985), but it is also related to Laukkanen (2001) who analyses the northern Baltic salmon fishery. We depart from Laukkanen's paper as we study the recreational river fishery in more detail, while keeping the

[1] The demand for sport fishing has been analysed and estimated in a wide range of papers, including Anderson (1980b, 1983, 1993), Layman et al. (1996), Green et al. (1997), Provhencer and Bishop (1997), and Schuhmann (1998). Studies of recreational versus commercial fisheries include McConnell and Sutinen (1979), Bishop and Samples (1980), Anderson (1980a), Rosenman (1991), Sutinen (1993), Cook and McGaw (1996), and Laukkanen (2001). Policy measures are analysed by Anderson (1993), and Homans and Ruliffson (1999).

marine fishery in the background. In addition, and in contrast to Laukkanen (2001) and Charles and Reed (1985), the control variable in our analysis is fishing permits, not catch. Moreover, we differ from the traditional recreational fishing literature (but see Anderson 1980b) in that we explicitly consider the distribution of benefits between anglers and landowners. Another contribution of our analysis is that we analyse gear regulations in the commercial and the recreational fishery under the various management scenarios. Although the application is for an Atlantic salmon recreational fishery, the model yields general results with policy relevance to other recreational fisheries in, say, Scandinavia and North-America.

The rest of the paper is structured as follows. In section two, we formulate the biological model and introduce harvesting. The cost and benefit functions are formulated in section three, and today's practice of myopic management is analysed in sections four and five based on price-taking and monopolistic landowners, respectively. In section six, we study the social planner solution, and in section seven, we present the numerical simulations. The paper concludes with some policy recommendations.

2. Population Dynamics and Biological Equilibrium

Building on Charles and Reed (1985), we consider a salmon sub-population whose size in biomass (or number of fish) at the beginning of the fishing season in year t is X_t. Both a marine and a river fishery influence the population during the spawning migration from its offshore environment to the coast and its parent river (´the home river`) where reproduction process takes place. A fixed fraction σ of the adult stock is assumed to leave the offshore habitat each year (Mills 1989) (cf. Figure 1). The marine fishery first influences the stock, because the marine harvest takes place in the fjords and inlets before the salmon reaches its spawning river. For a marine harvest rate $0 \leq h \leq 1$, $h\sigma X_t$ fish are removed from the population.

The escapement to the home river is accordingly $(1-h)\sigma X_t$. The river fishery exploits this spawning population along the upstream migration. When the river harvesting fraction is $0 \leq y_t \leq 1$, the river escapement is $(1-y_t)(1-h)\sigma X_t$. This spawning stock yields a subsequent recruitment $R((1-y_t)(1-h)\sigma X_t)$ to next year's stock. It is assumed that the stock-recruitment relationship $R(.)$ is purely compensating so that $R' > 0$ (more details below)[2]. The fraction of the recruits that survive is s_2. When a further (quite small) proportion s_1 of the spawners survives to be part of the stock the next year, and a proportion s_0 of the nonspawners staying offshore similarly survives (see e.g., Mills 1989 and 2000, for details), the population dynamics follows as:

(1) $$X_{t+1} = s_2R((1-y_t)(1-h)\sigma X_t) + s_1(1-y_t)(1-h)\sigma X_t + s_0(1-\sigma)X_t.$$

Figure 1 about here

Generally, when a single fish population is harvested sequentially by separate fisheries, as here, there will be conflicts between the different groups of harvesters because the size of h will influence the size of y_t, but the converse also applies through next year's fisheries. Hence, there will be reciprocal externalities present (see, e.g., McKelvey 1997). The present analysis is, however, restricted to studying the exploitation of the river fishery while taking the marine salmon fishery as *given*. The main reason for doing so is that we want to analyse the sport fishery thoroughly, as this is by far the most important part of the salmon fishery (see above). However, we do examine how the marine harvest affects the harvest and benefits of the

[2] As the juveniles usually spend several years in the river before they start their downstream migration and eventually join the offshore stock, the model represents a simplification of reality. This is due to the biomass approach, which could be made more realistic by a more detailed ecological model, including the age structure of the stock. Strictly speaking, therefore, each step in the time index t represents an average salmon generation life time (which varies between three and five years in different rivers) rather than one year. Laukkanen (2001) applies the same biomass approach.

recreational fishery, by analysing shifts in the (exogenous) marine harvesting rate. These shifts may be interpreted as changing restrictions imposed on the marine fishery, e.g. changes in season length, size and type of nets, and so forth.

Given the marine harvest rate, we focus on the river offtake $Y_t = y_t(1 - h)\sigma X_t$. As discussed further in the next section, the market for the salmon recreational fishery is related to the number of daily fishing permits D_t sold throughout the season (June–August). Accordingly, the number of fishing permits, or the number of fishing days spent in the river, represents the effort in the river fishery. We assume a harvesting function of the Schaefer type:

$$(2) \qquad Y_t = qD_t(1 - h)\sigma X_t,$$

where q is the catchability coefficient, related to the type of fishing equipment (fly fishing, fishing lure, spinning bait, and so forth)[3], and with $(1 - h)\sigma X_t$ as the stock available for sport fishing (see above). When combining the catch function (2), with the river offtake $Y_t = y_t(1 - h)\sigma X_t$, we find the harvesting fraction in the river simply as $y_t = qD_t$. Inserted into the population dynamic equation (1), the stock growth therefore yields $X_{t+1} = s_2R((1 - qD_t)(1 - h)\sigma X_t) + s_1 (1 - qD_t)(1 - h)\sigma X_t + s_0(1 - \sigma)X_t$. This may also be written as $X_{t+1} = F(X_t, D_t)$, where $\partial F / \partial D_t = F_D < 0$ holds. In addition, we find that $0 < F_X < 1$ under the present assumption of a pure compensatory stock-recruitment function ($R' > 0$).

When $X_t = X_{t+1} = X$ and $D_t = D$, the stock-effort equilibrium is written as:

$$(3) \qquad X = F(X,D).$$

[3] The assumption of a fixed catchability coefficient has been subject to criticism. Arrenguin-Sanchez (1996) provides a review.

Implicitly, this *biological equilibrium* condition defines the equilibrium stock as a function of the number of fishing days. Differentiation yields $(1 - F_X)dX = F_D dD$. Hence, more effort means a smaller stock. Therefore, the stock-effort equilibrium condition is decreasing in the $X - D$ diagram, and, where $D = 0$, it produces the highest possible stock level, whereas $X = 0$ gives the highest number of fishing days incompatible with an equilibrium fishery (see Figure 2 below). In line with intuition, it can be shown that the biological equilibrium shifts inwards if the marine harvest rate h shifts up. A higher catchability coefficient q shifts the biological equilibrium condition inwards as well.

Figure 2 about here

3. Demand and Cost Functions

We now introduce a market for sport fishing in our representative spawning river. On the demand side, there are a large number of potential recreational anglers, while there are a fixed number of landowners along the river who are given the right (by the State) to sell fishing permits (NOU 1999). These landowners are treated as a single agent, as they in most instances join forces and establish a river owner association. The competition from landowners in other rivers may vary. Crucial factors are the distance, which may vary between some few kilometres to over hundred kilometres, transportation costs, and various river-specific attributes. In most instances, the market situation is probably something between price-taking and monopoly behaviour (Skonhoft and Logstein 2003). However, we study both these market forms as stylized extremes.

As already mentioned, the market for salmon recreational fishery is related to the number of daily fishing permits sold (see also McConnel and Sutinen 1989, Anderson 1983, 1993, and

Lee 1996). Fishing permits may be for one day, one week, or a whole season. However, we collapse all these possibilities into one-day permits only, so that fishing demand is directly expressed in number of day permits, D_t. The sport fishermen's notion of the quality of the river is assumed to influence the demand. In line with McConnel and Sutinen (1979), this is expressed as the average catch per day, and for a given number of fishing days, a higher catch per day shifts the demand function upwards.

The inverse market demand for fishing licenses is hence given as:

(4) $$P_t = P(D_t, v_t) ,$$

where P_t is the fishing permit price per day and v_t is the demand induced catch per day. We have $v_t = \theta Q_t$ and, where catch per day (as a quality measure) from the catch function (2) is seen to be proportional to the river escapement, $Q_t = Y_t / D_t = q(1 - h)\sigma X_t$. The parameter $\theta > 0$ indicates how catch per day translates into demand. Obviously, the quality effect will vary between rivers and it may change over time. For these and others reasons, it is difficult to assess the strength of the quality effect, but on the whole, we may interpret θ as a parameter measuring how important the catch is compared to other factors influencing demand[4]. Hence, in addition to $P_D < 0$, we have $P_v > 0$.

When inserting catch per day into the inverse demand condition (4), the current profit of the landowners is:

[4] Using this simple demand function obviously means that many factors (income, average size of the fish caught, accommodations, congestion, and so forth) is neglected. However, our formulation seems to capture two of the most important demand elements. In a Norwegian survey, 92% of the sport fishermen reported that the quality of the river with respect to average catch per day was important. In addition, 72% reported that the price of fishing permits was important (Fiske and Aas, 2001).

(5) $\pi_t = P(D_t, \theta q(1 - h)\sigma X_t)D_t - C(D_t)$,

where $C(D_t)$ is the cost function, covering fixed as well as variable costs with $C'(D_t) > 0$ and $C''(D_t) \geq 0$. Fixed costs include various types of costs associated with preparing the fishery (constructing tracks, fishing huts, and so forth), whereas variable costs include the costs of organizing the fishing permit sales together with enforcement.

We assume that the landowners supply fishing permits based on *current* economic and biological conditions. There may be various reasons leading to myopic management, most important is the insecure state of property rights due to the marine harvest. This *myopic* behaviour seems to be in accordance with the stylized facts management situation in the Norwegian salmon river fishery (Skonhoft and Logstein, 2003), and is the same resource management scheme studied in numerous papers.

4. Price-Taking Landowners

First, we look at the situation where fishing permits are supplied under price-taking behaviour, for example because the river is located in a fjord close to other rivers. When also supplying fishing permits under myopic conditions, the landowners maximize their current profit (5) with respect to the number of fishing permits, while taking the price as well as the stock as given. We then simply have the first order condition:

(6) $P(D_t, v_t) - C'(D_t) = 0$.

Equation (6) defines the function $D_t = D^P(X_t)$ (superscript 'P' is for price-taking behaviour). When inserted into the population dynamic equation (1), or $X_{t+1} = F(X_t, D_t)$, we obtain $X_{t+1} = F(X_t, D^P(X_t))$. This is a first order non-linear difference equation that, in principle, may exhibit all types of dynamics (see the classical May 1976). Therefore, the present myopic management scheme does not automatically secure any long-term equilibrium, or steady state. However, it should be noted that there is a strong demand-side stabilizing effect as demand responds to the stock size through the quality factor. On the other hand, parameters in the stock-recruitment and harvesting functions may work in a destabilizing manner (more on this below).

Supposing that a steady state exists, the first order condition (6) represents the *economic equilibrium* condition, where differentiation yields $[P_D - C'']dD = -\theta q(1-h)\sigma P_v dX$. As the left-hand side is negative, due to the second order condition for the maximum, we find that this equilibrium condition, if existing, is positively sloped in the $X - D$ plane. Thus, in line with intuition, a higher stock size is associated with more fishing days in economic equilibrium (Figure 2 below). Therefore, the intersection with the negatively sloped biological equilibrium condition (2) represents the (unique) *bioeconomic equilibrium* X^P, D^P under the present myopic price-taking management scheme.

The total surplus of the fishery comprises the landowner profit and the angler surplus (consumer surplus). At a given point of time, as well as in the steady state, the angler surplus is given by the area under the inverse demand function for a given stock size (or the given demand-induced catch per day). A higher stock size for the same market price yields a higher angler surplus, as the inverse demand function shifts up. However, as the stock is not controlled by the landowners or the anglers, X^P is considered to be an externality determining the value of the angler surplus, as well as the profit (Anderson 1983). This will also be the case outside the bioeconomic equilibrium.

Throughout the reminder of the paper, two important comparative static as well as dynamic effects are analysed; the effects of changes in the marine harvest rate h and the catchability coefficient q. As mentioned above, a shift in the marine harvest rate may be interpreted as changes in the restrictions imposed on the marine fishery by the State. Likewise, a shift in the catchability coefficient can be related to new gear regulations in the river fishery where, say, a reduction in q may be due to banning of different bate types[5].

It can easily be shown that a higher marine harvest rate h shifts the economic equilibrium condition outwards, meaning that lower effort is compatible with the same fish stock. As a higher marine harvest rate shifts the biological equilibrium inwards (see above), we therefore find that the number of fishing permits decreases, whereas the equilibrium stock effect is generally ambiguous. If the demand response is weak, the stock will decrease with a higher marine harvest rate h. On the other hand, if the demand response is strong; that is, the quality parameter θ is high in value, we may find that the equilibrium stock increases (more on this in the numerical examples below). An increased catchability coefficient q (e.g. relaxed gear restrictions) shifts the economic equilibrium condition inwards. As the biological equilibrium condition shifts inwards (see above) with a higher q, we hence find that the equilibrium stock (if existing) decreases, while the effect on the number of fishing days is ambiguous. It can be shown that the sign of this effort effect depends on the demand response through θ. We therefore have that while relaxing the gear restrictions in the recreational fishery always decreases the salmon stock, relaxing the restrictions in the marine fishery may in fact increase the stock through reduced recreational demand (see also numerical section below).

[5] Fiske and Aas (2001) present an overview of the efficiency of different angling methods in recreational salmon fishing.

The total surplus and the surplus distribution between landowners and anglers will be influenced by all parameter changes. The outcomes are generally quite complex because of the quality effect in the demand function. If a higher marine harvest fraction h is accompanied by a smaller stock, together with a lower number of fishing permits, the angler surplus decreases. This may also be the case for the landowner profit (but not with constant marginal cost, see below). However, which of these components that is reduced most, depends on circumstances. The picture is even more complex if a higher h is accompanied by more salmon (more on this in the numerical analysis).

5. Monopolistic Landowners

We now turn to the other stylised management scheme where the landowners may act as monopolistic suppliers of fishing permits, for example because the river is located far away from other rivers. Under monopolistic and myopic behaviour, maximizing (5) with respect to D_t yields the first order condition:

$$(7) \qquad P(D_t, v_t) + P_D(D_t, v_t)D - C'(D_t) = 0.$$

Equation (7) defines the function $D_t = D^M(X_t)$ (superscript 'M' is for monopolistic behaviour). Inserted into the population growth function (1), or $X_{t+1} = F(X_t, D_t)$, yields a first order non-linear difference equation, as before. It is difficult to say how this difference equation behaves in comparison with the price-taker situation. However, as this management scheme is more conducive to the conservation of stock (see below), one suspects that fluctuations, if any, will decline. We come back to this issue in the numerical simulations.

Supposing that a steady state exists, the first order condition (7) yields the *economic equilibrium* condition under the monopolistic supply assumption, X^M and D^M.

Differentiation gives $[2P_D + DP_{DD} - C'']dD = -\theta q(1-h)\sigma[P_v + DP_{Dv}]dX$, where the term in the bracket on the left-hand side is negative again, due to the second order condition. Under the reasonable assumption that the quality effect dominates the potentially negative cross effect in the demand function, so that $[P_v + DP_{Dv}] > 0$, we find that the economic equilibrium condition again is positively sloped in the *X–D* diagram. However, it is less positively sloped than the economic equilibrium condition under price-taking behaviour. Notice also that the interceptions of the first order conditions (6) and (7) with the X axis are the same (again, see Figure 2). For these reasons, as expected, the bioeconomic equilibrium stock is higher and the number of supplied permits is lower than under price-taking behaviour; that is, $X^M > X^P$ and $D^M < D^P$.

While the price-taking scheme yields more fish and less effort in bioeconomic equilibrium than the monopolistic scheme, the total surplus will not necessarily be higher. The reason is that the quality effect in the demand function works like an externality (see also above). Hence, higher profit may dominate a reduced angler surplus when moving from the myopic price-taking scheme to the myopic monopolistic scheme (cf. the numerical results). Depending on how the demand curve shifts, it is possible, at least in theory, that the angler surplus can increase when moving to the monopolistic scheme.

6. The Social Planner Solution

The above myopic management regimes are now contrasted with the social planner solution, where the goal is to maximize the present value overall economic benefit, comprising the profit of the landowners as well as the angler surplus (consumer surplus), while taking the population dynamics into account. Hence, the goal of the social planner is to maximize $\sum_{t=0}^{T-1} \rho^t [P(D_t, v_t) D_t - C(D_t)] + \rho^T J(X_T)/\delta$ without taking the downward-sloping demand schedule into account. T is the planning period, and $\rho = 1/(1+\delta)$ is the discount factor, with $\delta > 0$ as the (yearly) discount rate, whereas $J(X_T) = [P(D_T, v_T)D_T - C(D_T)]$ is the scrap-value function. Therefore, it is assumed that the resulting stock X_T can be sustainably harvested forever.

To fit this optimization problem to the standard discrete-time optimal control format, the population dynamics is rewritten as $X_{t+1} - X_t = F(X_t, D_t) - X_t$. The current value Hamiltonian of this problem then reads (see, e.g., Conrad and Clark 1995) as $H(X_t, D_t, \lambda_{t+1}) = [P(D_t, v_t)D_t - C(D_t)] + \rho\lambda_{t+1}[F(X_t, D_t) - X_t]$, where $\lambda_t > 0$ is the resource shadow price. The first order conditions yield:

(8) $\quad P(D_t, v_t) - C'(D_t) + \rho\lambda_{t+1} F_D(X_t, D_t) = 0$; $t = 0,\ldots,T-1$,

and

(9) $\quad \rho\lambda_{t+1} - \lambda_t = -P_v(D_t, v_t)\theta q\sigma(1-h)D_t - \rho\lambda_{t+1}[F_X(X_t, D_t) - 1]$; $t = 1,\ldots,T-1$,

when assuming an interior solution (a positive supply of fishing permits at the steady state). In addition, we have the transversality condition $\lambda_T = J'(X_T)/\delta$.

The interpretation of control condition (8) is that fishing permits should be supplied up to the point where the licence price is equal to the marginal cost of the suppliers plus the cost of reduced stock growth, evaluated at the shadow price. Equation (9) is the portfolio condition governing the change of the resource price. Basically, it states that the biomass should be maintained so that the change in the net natural growth is equal to the (shadow) price change, adjusted for the discount factor. As the Hamiltonian is not linear in the control, we typically find that the dynamics will not be characterized by a Most Rapid Approach Path (*MRAP*) but will be close to this type (see the numerical analysis).

Suppose that a steady state exists and is reachable from X_0. Evaluating (8) at the steady state implies $\lambda = -[P(D, v_t) - C'(D)] / \rho F_D(X, D)$. Substituting (8) into (9), also in the steady state, and rearranging, we obtain the discrete time golden rule condition**:**

$$(10) \qquad F_X(X, D) - \frac{\left[P_v(D, \theta Q)\theta q \sigma (1-h) D\right]}{P(D, \theta Q) - C'\left(D\right)} F_D(X, D) = 1 + \delta ,$$

which states that the internal rate of return of the resource should be equal to the external rate of return (1 + δ). Therefore, the golden rule condition, together with the biological equilibrium condition (3), yields the social planner steady state X^* and D^*.

The steady state of the social planner solution may be compared to the steady states (if existing) under myopic management. It is straightforward to demonstrate that the control condition (8) in economic equilibrium will be located further outward than equation (6) in equilibrium, because $F'_D < 0$ and $\lambda > 0$ (again, see Figure 2). Therefore, we can conclude that the steady-state stock level will be higher and the number of fishing permits will be lower than under the myopic price-taking scheme; that is, $X^* > X^P$ and $D^* < D^P$. Consequently, the fishing permit price following myopic price-taking management will always be below the social planner solution. Comparing with the monopolistic myopic solution (7) indicates that the social planner solution, depending on the difference $(P_D D - \rho\lambda F_D)$, will be located between the price-taking solution and the monopolistic solution. Notice that the interception with the X axis will be the same as in the myopic regimes because the shadow price of the stock is zero whenever there is no permit sale.

However, it is not possible to infer anything definite about the distribution of benefits between the anglers and landowners. The total current surplus in the myopic equilibria may be higher than the social planner solution due to discounting[6]. It can be shown that a higher periodic discount rate will increase the slope of the control condition (8) in equilibrium. Consequently, as expected, the steady state of the social planner solution approaches the price-taking myopic management solution. In the limiting case with $\delta = \infty$, we find that the social planner solution coincides with the equilibrium price-taker myopic management situation. The steady-state total surplus and the distribution of the surplus are then equal in these regimes. When $\delta = 0$, the steady state of the planner solution coincides with the problem of maximizing the total current surplus in biological equilibrium while taking into account this equilibrium[7]. Then, the total current surplus in equilibrium is obviously higher in the social planner solution than in the myopic price-taking situation. However, for intermediate values of the discount rate the opposite can hold. This will also be the case when comparing the social planner solution with the myopic monopolistic scheme.

7. Numerical Analysis and Results

[6] However, the present-value total surplus is obviously higher under the social planner solution than the present-value total surplus of the myopic solutions for the same time period and discount rate.
[7] These results are the same as we find in the standard Clark harvesting model (see, e.g., Munro and Scott 1985).

7.1. Data and specific functional forms

The above analysis will now be illustrated numerically with data from the river Imsa. This is a typically small, but productive, salmon river located on the southwestern coast of Norway (for details, see Hansen *et al*. 1996). We start by specifying the functional forms. The stock-recruitment function is given as the Cushing curve version of the Shepherd function (Shepherd, 1982, King, 1995):

$$(11) \qquad R = R((1-qD_t)(1-h)\sigma X_t) = r\frac{(1-qD_t)(1-h)\sigma X_t}{1+\left[\frac{(1-qD_t)(1-h)\sigma X_t}{K}\right]^{\gamma}},$$

where $(1 - qD_t)(1 - h)\sigma X_t$ is the spawning biomass (see section 2 above), $r > 0$ is the intrinsic growth rate interpreted as the maximum number of recruits per spawning salmon, and $K > 0$ is the stock level for which density dependent mortality equals density independent mortality. Finally, the compensation parameter $\gamma > 0$ indicates to what extent density independent effects compensate for changes in the stock size. The parameter values are estimated by Hansen *et al*. (1996) for Imsa and are reported in the Appendix. Here, it can be seen that we have $\gamma < 1$ and the density-dependent effect is weak. Consequently, as already indicated, the stock-recruitment function (11) is increasing for all levels of the spawning population, $R' > 0$.

The inverse demand function is specified as linear. In addition, it is assumed that the quality of the river, approximated by catch per day, $Q = q(1 - h)\sigma X_t$, shifts the demand uniformly up:

$$(12) \qquad P_t = \alpha\theta q(1 - h)\sigma X_t - \beta D_t.$$

Accordingly, the choke price α gives the maximum willingness to pay when the quality-translated catch is one fish per day, whereas β reflects the price response in a standard manner. The cost function is given linear as well:

$$(13) \qquad C_t = c_0 + cD_t \, ,$$

so that c_0 is the fixed cost, while c is the constant marginal cost of providing a fishing permit (see also section 3 above). Based on the above demand and cost functions, we find that the first order condition under the myopic price taking and monopolistic scheme are $\alpha\theta q(1 - h)\sigma X_t - \beta D_t = c$ and $\alpha\theta q(1 - h)\sigma X_t - 2\beta D_t = c$, respectively. It is therefore a linear, increasing relationship between stock size and the number of fishing days, and the slope of the economic equilibrium condition under price taking will be two times higher than that of the monopolistic case (cf. also Figure 2). The economic parameter values are found in the Appendix as well.

7.2. Steady state

First, we look at the steady states. For the baseline parameter values, the steady state will be approached smoothly under all three management schemes. It can be seen in Table I that the monopolistic myopic regime is somewhat more stock conserving than the social planner solution. As demonstrated above, the reason for this is that, in order to increase profit, the monopolist reduces demand more than does the social planner, who accounts for the future stock value. When the landowners face competition and act as price takers, the stock is substantially lower. On the contrary, and consistent with this, permit sales are higher and the license price is lower. Because of the constant marginal cost assumption, the price under the price-taking scheme just equalizes this value.

Table I about here

In addition, under the baseline parameter values, it can be seen that the total surplus (angler and landowner surplus) in the social planner solution and the monopolistic case are equal. This happens by accident, but as noted above it is possible that the steady-state total surplus in the myopic monopolistic case (as well as under price taking) can exceed the social planner solution due to discounting (section 6 above). The total surplus in the myopic monopolistic case is above that of the myopic price-taking case. As explained in section 5, the reason for this is the quality shift in the market demand function. However, the anglers are substantially better off under the myopic price-taking scheme irrespective of the fact that the quality of the fishing experience, measured as catch per day, is lowest here. Thus, the low fishing license price more than compensates for the low quality. Note also that the angler surplus is higher under the price-taking regime than under social planner solution as well.

Table I reports the results when the catchability coefficient increases by 20% due to relaxed gear restrictions. The stock abundance becomes substantially lower under the price-taking scheme while the stock effects are more modest in the monopolistic case and social planner case due to the increased fishing permit price. The catchability shift materializes into small changes in the angler surplus, while the landowner surplus increases most under the social planner solution. Moreover, since the total surplus increases with more efficient fishing equipment the opposite occurs when gear restrictions are imposed.

Table II demonstrates how changes in the marine harvest rate h affect the steady-state river fishery, where $h = 0.4$ is the baseline value (cf. also Table I). A higher marine harvest rate through relaxed harvesting restrictions has an ambiguous stock effect under both myopic schemes, whereas the stock decreases under the social planner solution. If the quality demand effect is strong, we hence obtain the somewhat paradoxical result that a higher marine harvesting pressure goes hand in hand with more fish (section 4 above). Note that this is the exact opposite stock effect of that obtained by relaxing the gear restrictions in the recreational fishery under the myopic schemes (see discussion above). Under the social planner solution, on the other hand, a higher *h* translates consistently into a smaller stock because the stock shadow price, from a river management point of view, depends on the fish biomass entering the river. Hence, when the marine harvest rate increases, the shadow price decreases. A higher *h* generally reduces the surplus.

Table II about here

7.3. Dynamics

For the given specific functional forms, the first order myopic profit maximum conditions yield linear relationships between the number of fishing days and the stock. We have $D_t = D^P(X_t) = (1/\beta)[\alpha\theta q(1-h)\sigma X_t - c]$ in the price-taking case and $D_t = D^M(X_t) = (1/2\beta)[\alpha\theta q(1-h)\sigma X_t - c]$ in the monopolistic case (cf. sections 4, 5, and 7.1). Therefore, these equations, combined with the population growth function (1), or $X_{t+1} = F(X_t, D_t)$, and the stock-recruitment function (11), yield the first order non-linear difference stock equations under the myopic schemes to be studied here.

Figures 3a and 3b demonstrate the dynamics for the baseline parameterization of these myopic schemes. In contrast, Figure 3c shows the social planner solution where the planning horizon is infinite (see Appendix). The initial stock size is assumed to be quite modest

($X_0 = 50$), so these transitional growth paths demonstrate recovery from a previous situation involving serious overfishing. The steady states are reached rapidly, with negligible overshooting, and the dynamics are quite similar under all three management scenarios. The social planner solution seems to be close to *MRAP* (see section 6 above). As mentioned, the basic stabilizing factor is the quality factor in demand; that is, a low stock is accompanied by a modest demand and the stock rebuilds smoothly. Starting with other initial values gives more or less the same picture, leading to the unique steady states.

Figure 3 about here

Although the steady states under myopic management seem to be quite stable given the baseline parameter values, other ecological and economic conditions may produce instability. We find that relaxing the gear restrictions and thereby increasing the recreational fishery catchability coefficient q may induce all types of dynamics. For example, the dynamics will exhibit a two-point cycle pattern (see, e.g., Conrad and Clark 1987) if q increases by 35 % (see Figure 4). Such a shift will not produce cycles in the monopolistic case but rather result in an initial overshooting (not shown).

Figure 4 about here

We have also studied the dynamics when the marine harvesting pressure changes. Under myopic price-taking behaviour by landowners, it turns out that lower marine harvest activity may produce instability. If gear restrictions reduce the marine harvest pressure from the baseline level of 0.4 to 0.2, the stock exhibits damped oscillations (Figure 4). If h shifts further down to just 0.1, the dynamics will be of the two-point cycle type. An even further reduction down to zero, interpreted as a marine harvesting ban, leads to a chaotic pattern. Thus, the initial value of the stock is crucial for the dynamics. The reason why low marine harvest rates work in the direction of instability is that, as the marine harvest rate decreases, more salmon enter the river and produce an upward shift in the market demand function through the quality effect. Hence, at least in the initial stage, the effect is an upward shift in demand due to an increased willingness to pay.

8. Concluding Remarks

This paper examines two myopic management regimes in a recreational river fishery and contrasts these with the social planner solution. The management schemes are evaluated in terms of profitability, angler surplus, effort use, license price, and stock size. The marine harvesting activity is given throughout the analysis. Both the steady states and dynamic paths are examined. It is generally unclear how the various harvesting schemes distribute total surplus between anglers and landowners. This hinges critically on the uncertain stock and effort effects under the different management scenarios.

It has traditionally been argued that the recreational fishery is of minor importance to the wild Atlantic salmon stock abundance because the escapement needed to ensure recruitment is quite low (see introduction). Thus, NASCO (2001) regards low marine survival as the crucial factor determining the decreasing wild stock. We offer an alternative explanation as we have shown that, even with a constant marine survival, large stock fluctuations may be due to type of river management. Moreover, we demonstrate that an increased marine harvesting activity may in fact be stock conserving under myopic management.

The analysis indicates some policy and regulation implications. First, measures taken to reduce the marine harvesting activity may produce unclear stock effects as well as large stock fluctuations. The crucial factor here is how strong the demand quality effect is. As seen, this hinges critically on type of management scheme in the river, and in the myopic case we find that a reduced marine harvest rate may go hand in hand with a reduced stock. Imposing gear restrictions in the river generally increases the stock and decreases total surplus, but may also lead to reduced stock fluctuations over time. Thus, imposing gear restrictions in the marine fishery may have the exact opposite stock effects of imposing restrictions in the recreational fishery. The dynamic properties may also be of the opposite. One additional straightforward measure to reduce fluctuations under price-taking myopic management is to impose a tax equal to the shadow price of the stock. This would ensure stock and effort levels equivalent to those under the social planner solution.

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Appendix

The ecological parameter values are based on Hansen *et al.* (1996) (see also Skonhoft and Logstein, 2003), whereas some of the key economic parameter values are calibrated to ensure the resulting prices and catches are realistic. The (fixed) marginal cost of the landowners, which is given as $c = 50$ NOK per day, is crucial here, as is the quality response in demand, which is fixed at $\theta = 1$. The steady-state fishing licence price under myopic price-taking management then becomes 50 NOK per day, whereas catch per fishing day is 0.72 (salmon per day) under the baseline scenario. These and other values fit reasonably well with a small salmon river fishery according to NOU (1999) and Fiske and Aas (2001).

Figure AI about here

The marine harvest rate varies considerably over time, but has declined significantly during the last few years (see section one in the main text, NOU 1999). We use 0.4 as the baseline value. The myopic scheme then yields approximately the same river catch (in number of salmon) as the marine catch, which again fits reasonably well with a small river fishery. The planning period under social planning is set at $T = \infty$ in the simulations.

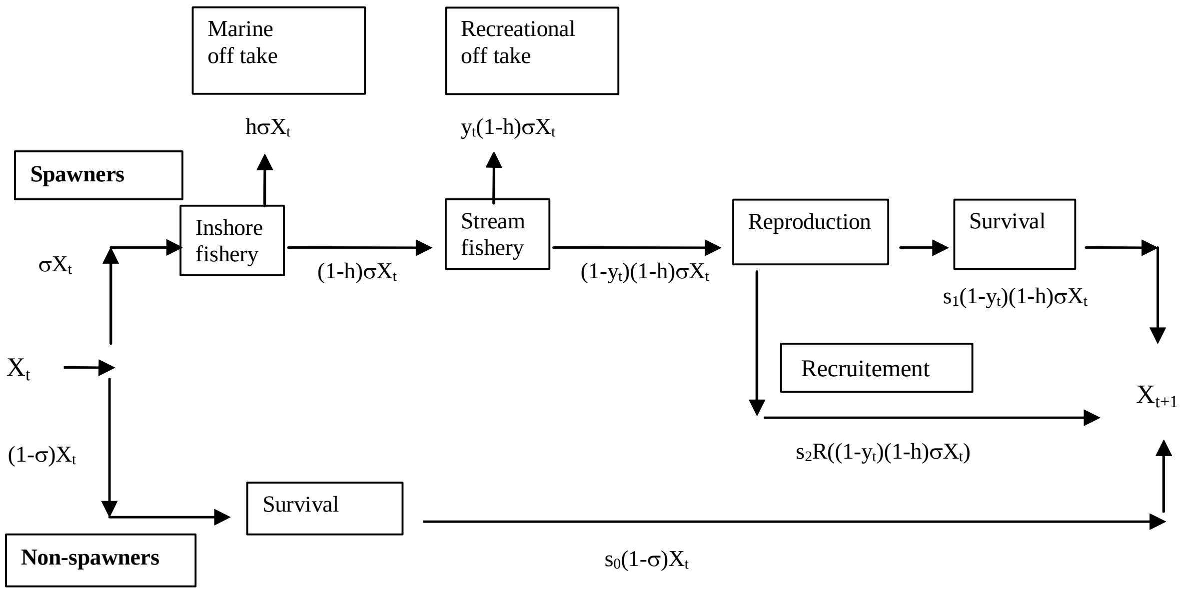


Figure 1. Harvest and growth

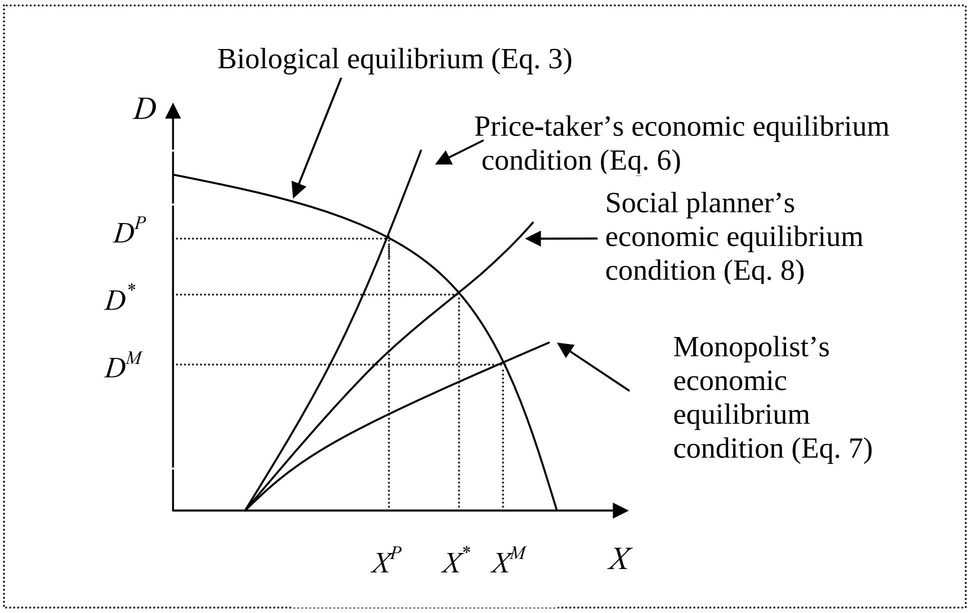
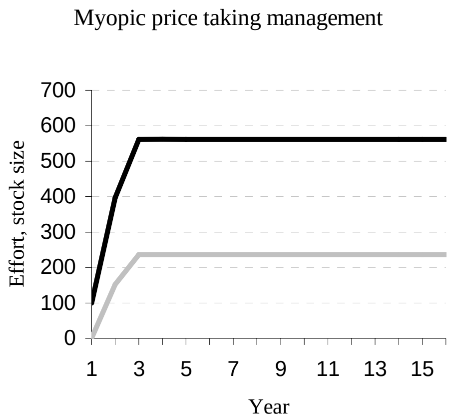
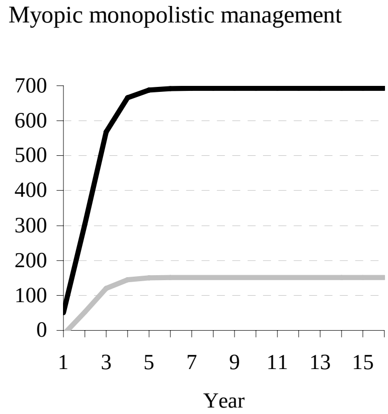


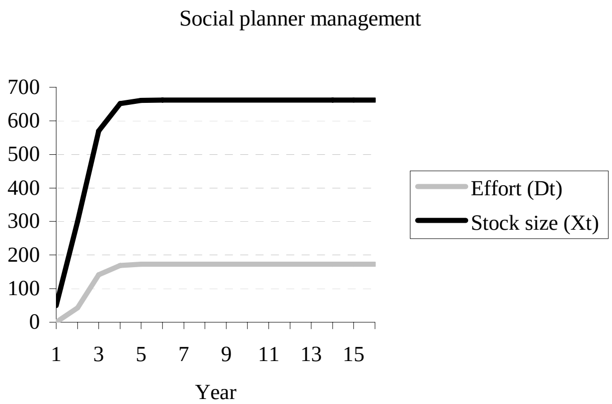
Figure 2. Economic and biological equilibrium, myopic management, price taking (*P*) and monopolistic (*M*) landowners, and under the social planner solution (*).



a)

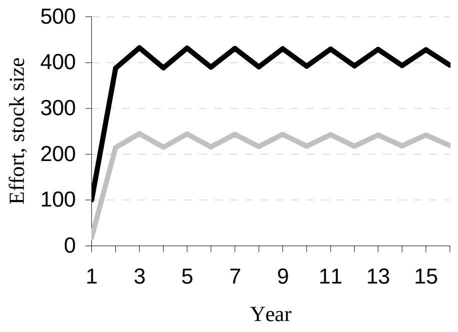


b)

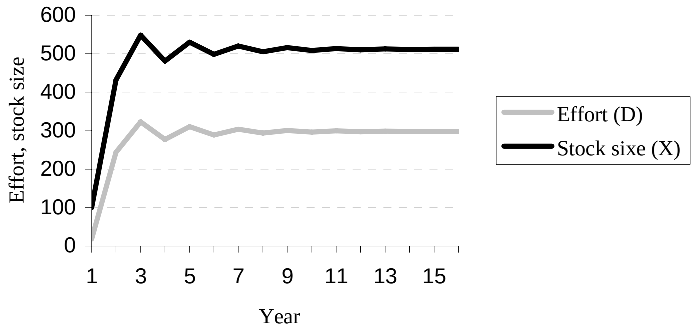


c)

Figure 3: Dynamic paths. Baseline parameter values. Stock size X_t (number of salmon), effort in number of fishing days D_t. Myopic price taking scheme (a), Myopic monopolistic scheme (b), Social planner solution (c)



a)



b)

Figure 4. Dynamic paths myopic price taking. Stock size X_t (number of salmon), effort in number of fishing days D_t. The catchability coefficient q increased by 35% (a) The marine harvest rate, h, decreased from 0.4 to 0.2 (b).

Table I. Steady state. Stock size *X* (number of salmon), number of fishing days *D*, permit price *P* (NOK per day), landowner surplus *LS* (1000 NOK), angler surplus *AS* (1000 NOK) and total surplus *TS* (1000 NOK).

	Parameter values	Myopic Price taker	Myopic Monopolist	Social planner management
X	*Baseline values*	**562**	**692**	**665**
	Catchability ↑	469	623	628
D	*Baseline values*	**237**	**152**	**171**
	Catchability ↑	237	166	163
P	*Baseline values*	**50**	**201**	**168**
	Catchability ↑	50	216	221
LS	*Baseline values*	**0**	**23**	**20**
	Catchability ↑	0	27	28
AS	*Baseline values*	**28**	**12**	**15**
	Catchability ↑	28	14	13
TS	*Baseline values*	**28**	**35**	**35**
	Catchability ↑	28	41	41

Table note: Catchability ↑; the catchability coefficient q increases 20%.

Table II. Steady state. Different marine harvest rates. Stock size *X* (number of salmon), number of fishing days *D*, permit price *P* (NOK per day), landowner surplus *LS* (1000 NOK), angler surplus *AS* (1000 NOK) and total surplus *TS* (1000 NOK).

	Marine harvest rate h				
	0.0	0.2	0.4	0.6	0.8
Myopic price taking management					
X^P	453	512	562	573	482
D^P	335	298	237	145	32
P^P	50	50	50	50	50
LS^P	0	0	0	0	0
AS^P	56	44	28	10	1
TS^P	56	44	28	10	1
Myopic monopolistic management					
X^M	671	696	692	638	495
D^M	260	212	151	83	17
P^M	310	261	202	134	67
LS^M	68	45	23	7	0
AS^M	34	22	11	3	0
TS^M	102	67	34	10	0
Social planner solution					
X^*	765	715	665	604	486
D^*	219	202	171	116	29
P^*	431	284	168	89	54
LS^*	83	47	20	5	1
AS^*	24	20	15	7	0
TS^*	107	67	35	12	1

Table AI. Baseline values prices and costs, ecological parameters and other parameters

Parameter	Parameter description	Value
r	*-Maximum recruitment per spawning salmon*	124 (smolt per spawning salmon)
K	*-Stock level where density dependent mortality dominates density independent factors*	5.3 (number of spawning salmon)
γ	*-Degree to which extent density-independent effects compensate for stock changes.*	0.77
σ	*-Fraction of non-spawners*	0.85
s_0	*-Survival rate non-spawners*	0.5
s_1	*-Share of salmon spawning twice*	0.25
s_2	*-Survival rate, downstream smolt migration*	0.4
α	*-Reservation price when catch per day is 1*	400 (NOK/salmon)
β	*-Price effect demand*	1 (NOK/day^2)
c	*-Marginal cost fishing permit sale*	50 (NOK/day)
c_0	*-Fixed cost fishing permit sale*	0
q	*-Catchability coefficient*	0.0025 (1/day)
h	*-Marine harvest rate*	0.4
δ	*-Period discount rate*	0.07
θ	*-Quality response in demand*	1