

Interlocked sustainable use of multiple fish stocks — modelling biological and socio-economic conditions in Finnish vendace (*Coregonus albula* (L.)) fisheries

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Using economic and historical yield data models in this paper we outline the socio-economic and ecological conditions for sustainable use of fish resources in commercial lake fisheries in Finland, in the context of fragmented private ownership and owner-based management. Interlocked use refers to area greater than the typical current area on one or two lakes, and that could be used as a joint resource by the fishers in the area. The results of the economic model show that the management of the interlocked fishery, in particular by encouraging mobility of fishers, can produce higher sustainable economic benefits from the fishery. The yield data analysis shows that an interlocked resource may considerably decrease fluctuations of yield in commercial vendace fisheries. This implies that the interlocked use approach would increase the cost-effectiveness and decrease the interannual variability in income to the fishers, thus promoting sustainability in the fishery and making it potentially a more viable livelihood in rural areas.

Introduction

A principal characteristic of biological natural resources is the spatial and temporal fluctuation of populations. In many animal populations, this fluctuation is mostly stochastic but may appear as cycles, waves and synchrony within a wide geographic area (Moran 1952, Myers *et al.* 1997, Bjørnstad *et al.* 1999). Fisheries science has long endeavoured to develop management practices which could diminish inter-annual fluctuation of the yield. One method has been to adjust the exploitation rate to a level which ensures

adequate yield with tolerable variation. In a fishery targeting small schooling fishes, this aim has proved to be difficult or impossible to achieve (Cirke 1988), so fishers have had to adjust their operations to the dynamics of the population they utilize. In inland fisheries, a new possible practice is the integrated use and management of a combined resource consisting of several lakes. This strategy is here called the *interlocked sustainable use of multiple fish stocks*, and the main implication of the practice is optimal allocation of fishing effort following the spatial dynamics of the resource. This requires increased mobility

of a proportion of the fishers.

This study concerns vendace (*Coregonus albula* (L.)) which is the main target species for the commercial fisheries on Finnish inland waters. Its annual yield varies from 1000 to 4000 metric tons and value from 1.7 to 5.4 million euros. There are ca. 1000 commercial fishers on Finnish inland waters, representing 25% of the total number of Finnish commercial fishers (Finnish Game and Fisheries Research Institute, FGFRI 2001). Vendace is either the most important or only target species for the majority, ca. 70%, of commercial inland fishers and they typically exploit one or two nearby lakes (K. Muje unpubl. data). There is a high demand for vendace on fish markets based on the fine flavour of its flesh and versatility for processing and cooking. This is hindered, however, by shortcomings in making products more suitable for wider markets and by the relatively small size of the enterprises (Käyhkö *et al.* 1997, Abbors 1998).

Sustainability of the fishery in context of private ownership

The social context

The maintenance and development of commercial vendace fishing is rendered difficult by several interlinked obstacles, in all major subsystems of the inland fisheries system, namely biological, socio-economic and political-administrative subsystems (e.g. Sipponen 1999).

A major challenge for sustainability is the fragmented ownership system. Land tenure is closely connected to the right to use and control the use of the fish resources (Sipponen 1999). Since the 1960s, urbanisation and depopulation of the countryside, and resulting division of landowners into non-local and local interest groups, has raised ownership- and use-interest related issues at the local level of fishery management (shareholders associations) (Muje 1995, Salmi & Muje 2001, Tonder & Muje 2002). Typically there are several shareholders associations within one lake, and along any major watercourse up to several hundred. As a result, the areas of shareholders associations are not necessarily related naturally to the structure

of the watercourses. The land estates belonging to one shareholders association are defined based on the purpose of property formation, not on functionality. The shareholder estates do not necessarily have any functional connection with each other in a shareholders association (Viher-vuori 1988). However, the shareholder estates are typically situated near each other.

At present, the ownership in shareholders associations is to a considerable extent non-localized. Thus, shareholders have come to represent a wider scale of interests, both in terms of locality and type of use of the resource (Tonder & Muje 2002). Yet due to a number of problems in participation in shareholders associations, the decision-making is strongly in the hands of local shareholders. Among them, commercial fishers usually have a minor representation (Muje *et al.* 2001). This fragmentation, along with a tradition of local decision-making, has proved problematic for commercial fisheries. The needs of commercial fisheries and other uses that require wide areas have often been overshadowed by the more prominent local needs of those landowners, who are active in the management. On the other hand, the fishery authorities and regional management bodies (Fisheries regions) have no strict means to unify locally based decisions.

The fragmentation of ownership and its consequences have evolved over several decades. At present the commercial fishers use lakes that are close to their residence — a tendency which seems to be enhanced by the shareholders associations policy to sell licences almost exclusively to local fishers. Fishing is often allowed only on a limited area of each lake, due to some of the shareholders associations reluctance to sell licences to their small areas. Even when use of separate lakes is possible for some local fishers, the fishery in these kinds of multiple stocks is not open for all commercial fishers. Therefore, the present utilization of vendace stocks depends to a great extent on the dynamics of populations within a relatively limited geographical area.

Sustainability

Sustainability of the fishery may be viewed as consisting of four factors: ecological, socio-

economic, community and institutional sustainability (Charles 2001). In this paper we focus on the two first aspects, and outline consequences to community and institutional sustainability in the discussion. The key issue is whether, in the context of interlocked use, the four aspects of sustainability can be attained simultaneously.

Ecological sustainability

The basic constraint on exploiting the vendace produced from the biological subsystem is the large and unpredictable population fluctuation (Karjalainen *et al.* 2000). Variation in the strength of successive year-classes of vendace can be from one to two orders of magnitude. Since vendace is a short-lived fish with potential for enormous reproduction, its yield is usually composed of practically only one year class at a time (Karjalainen *et al.* 2000). Despite this, ecological sustainability of vendace populations (in the sense of avoiding excessive fishing that endangers future reproduction) seems to be relatively easy to achieve. Commercial fishing is often stopped due to economic reasons before the stocks decline to a permanently low level (Marjomäki *et al.* 1995). On the other hand there are observations that suggest effective compensatory regulation of recruitment (Valtonen & Marjomäki 1988, Salojärvi 1991, Salmi & Huusko 1995b) and growth (Marjomäki & Kirjasniemi 1995) in dense populations.

At present a typical vendace fishery involves the use of trawls or winter-seines or both. Especially when using more than one lake, other catch species are often available, but with their share of the value of the annual catch being typically less than 20% they are not likely to set the terms for mobility of fishers (K. Muje unpubl. data).

In an interlocked fishing district, ecological sustainability would mean keeping the interlocked stock at a level that ensures both reproduction and surplus production for the fishery within a time-period that encompasses the natural stock fluctuation range (from high to low stock). This requires that during natural low-stock periods commercial fishing in certain lakes is severely restricted or halted, and for high-stock periods that information is gained on

the effect of increased fishing effort on stocks. Ecological sustainability would be ensured here by adjusting fishing on separate stocks so that overexploitation is less likely.

Socio-economic sustainability

Socio-economic sustainability requires steady livelihoods, so that long-term planning and investment in the development of the profession, as well as in the fish processing and marketing, is possible based on the income that can be derived from the fishery.

The problem of unpredictable stock fluctuations is directly reflected to the socio-economic subsystem of the fisheries. Firstly, from the point of view of an individual fisher, it makes investment in development of fishing very risky as the low stock periods occur frequently and can last for several years or even a decade. Secondly, due to fluctuation, the supply of vendace to market is highly variable locally but also nationally as the low stock periods and population fluctuations in different lakes seem to be spatially correlated (Marjomäki *et al.* 2004). As the demand for fish is fairly constant, the variability of supply is reflected directly in the price and marketing possibilities of the fish. The price during a high stock period can be less than half of that during a low stock period. Usually the fishers are forced to strongly restrict their fishing effort in order to avoid excessive catches.

With the present geographical limits, economic sustainability in commercial fisheries is difficult if not impossible to achieve. Individual stocks are not abundant in all years, which is one of the main reasons why fishing provides less than half the income of most fishers. Yet fishing is an important contribution to the livelihood of several rural areas.

The question of sustainability in commercial fisheries draws together two issues:

1. Adaptation of livelihood to naturally fluctuating resources, and
2. Adaptation of livelihood to competition with other interests in the natural resources.

The first issue concerns the geographical

scale of the resources, which at present typically exceed the limits of management units. The second issue introduces (in addition to local interests) a range of non-local interests, many of which require wider areas than those of shareholders associations (Muje *et al.* 2001). Socio-economic sustainability is hence closely linked with ecological sustainability. More fish stocks available for the fishery could improve its economic performance and decrease uncertainty.

Practically all lakes could be utilized by several types of fishing. The competition that occurs between recreational or subsistence and commercial fishing is often based on the belief that (usually) the commercial fishery causes depletion. In the local decision-makers group, few share the commercial fishers' interest in economic utilisation (either by fishing or by selling licenses), or the need for unified management measures over an extensive area (Tonder & Muje 2002). The basic condition of social sustainability demands that all interest groups are somehow involved in the decision-making. This requirement is met by the institutional structure of the fishery management, but several problems occur in the participation and representation of some groups and in the cooperation of management bodies. In this context the most obvious problems are the minor representation of commercial fishers both in local and regional management, as well as minor representation of non-local owners in the shareholders associations (Muje *et al.* 2001). Local and regional management seem not to have adequate tools or incentive for placing sustainability clearly on the agenda in the case of commercial lake fisheries.

In this paper, we present two theoretical case studies in order to clarify the usefulness of the interlocked stock approach. The first analysis was based on the game theory model (*see* Lindroos 2000) which evaluates the equilibrium profits of fishers who may move freely between two lakes: one lake with high and the other with low fish production potential. Fishers compete in the fishery by taking into account the decisions of other fishers and the possibility to move to another lake. The fishery is in equilibrium when no single fisher finds it optimal to change lake and fishing effort. Under baseline conditions, the fishing intensity (fishing effort divided by area of the lake) in the high production lake was

greater than in the low production lake and the interlocked fishing intensity remained constant during the simulations.

In the second analysis, a 22-year time series of yield per unit of effort (YPUE, kg/seine haul) from three lakes (Salmi & Huusko 1995a) in Kuusamo, northeastern Finland, were used to reconstruct an interlocked fishing district for commercial vendace fishing. Two main questions asked in the second analysis were: is the variation in the interlocked YPUE lower than the variation in YPUE in each lake, and what is the catch-benefit if interlocked fishing effort was allocated only to the two lakes of highest YPUE in each year? In addition, a survey among commercial inland lake fishers was carried out ($n = 547$), dealing with the present situation concerning mobility in commercial fisheries, the main catch species and the willingness to participate in an interlocked fishing district. The unpublished data that are referred to in this paper are tentative results of this survey.

The concepts

The key concepts in this paper are derived from the concept of resource and the idea of interlocked use. The concept of resource is biologically based on fish stocks that can be defined as separate from other fish stocks. Interlocked refers to a larger unit, which is a sum of separate fish stocks in different lakes or in different parts of one lake, that can be managed as one (in a commercial fishery). In most cases the resource is utilized simultaneously by subsistence and recreational fishing. However, the economic model in the following section is based on competition between commercial fishers only. The yield-data model is based on the yield of commercial fishing in a situation where other uses (such as subsistence and recreational fishing) were present. The concept resource requires a wider definition, to include the various social and economic aspects in the use and management of lake-areas. The utilization of the fish stocks closely affects other uses of the lake and its shore. As this in turn affects the management of commercial fisheries in many ways, the concept may have to be applied to the total

lake-area within the designated interlocked area, be that one or more lakes or their parts. As this requires further research on social aspects of the interlocked use of the stocks, we hereby use the more clearly defined biological concepts of stock and interlocked stock in referring to the natural resource. The concepts used in this paper are:

- *interlocked equilibrium*: the equilibrium number of fishers on each lake and the equilibrium total fishing efforts by the fishers (interlocked effort);
- *interlocked fishing district*: the geographical area where the lakes (or parts of them) and stocks under exploitation are located;
- *interlocked fishing effort*: total sum of the fishing efforts in the lakes within the interlocked fishing area (e.g. seine hauls);
- *interlocked fishing intensity*: interlocked fishing effort divided by the total area of the lakes in the interlocked fishing district (e.g. seine hauls ha^{-1});
- *interlocked profit*: total profit of fishers from the two lakes;
- *interlocked stock*: sum of stocks under exploitation in a given interlocked fishing district as total number of fish in the interlocked stock or the area weighted mean of the fish density (individuals ha^{-1});
- *interlocked sustainable use of multiple fish stocks*: integrated use and management of the total resource of a given fish species in the interlocked fishing district consisting of several lakes;
- *interlocked yield*: total yield of a given species caught in the interlocked fishing district;
- *interlocked yield per unit of effort*: the mean YPUE of interlocked lakes weighted by the area of each lake (e.g. kg seine haul $^{-1}$);
- *interlocked yield potential*: the total annual standing crop of the interlocked lakes; total biomass of recruited fish in all lakes or the area weighted mean of the fish biomass (kg ha^{-1}).

Methods

The economic model

The economic model presented in this paper is

based on the game theory where, as a consequence of competition, the number of fishers in a given area may change. It is important to note that interlocked use strategy can be applied both with free competition and with different degrees of limited competition, where the number of fishers may be stable. In the latter case it is possible to achieve economic gain by more efficient use of multiple stocks (by increasing mobility). In all cases fishing intensity would be controlled by a management body.

The purpose of the economic model is to study the effect of fishing location choice on the biology and economics of lake fisheries. The fishers choose their fishing effort between two locations. This means that they can be active at lake 1 or lake 2, but not at both. If a fisher from lake 1 is active at lake 2, his mobility cost A_1 would be fixed. Similarly, a fisher from lake 2 harvesting in lake 1 would need to pay A_2 for transportation of the necessary gear. The fishers compare the expected profits of these two areas and choose the areas that yield them better profit. The fishery is in equilibrium if no single fisher finds it profitable to switch to another lake.

The two lakes differ in their production potential and number of fishers. Lake 1 (more productive lake) has a carrying capacity of K_1 and number of fishers locally resident is N_1 . Lake 2 (less productive lake) has carrying capacity K_2 with number of fishers N_2 ($K_1 > K_2$).

The lakes are assumed to be similar in size. Note that the stock sizes B_1 and B_2 may be different depending on how many fishers are fishing in that area. It is assumed that the fishers have perfect knowledge of the state of the stocks. Therefore, one factor that determines which lake the fishers choose is the amount of competition in the lakes. The efforts f_i and f_j denote the equilibrium efforts, which are functions of the number of fishers. Here i corresponds to lake 1 fishers and j to lake 2 fishers. The cost of travelling from lake 1 to lake 2 is A_1 while the cost of travelling from lake 2 to lake 1 is A_2 .

The model developed by e.g. Mesterton-Gibbons (1993) is followed, with a single stock of size B_1 (more productive lake) and B_2 (less productive lake) following the Gordon-Schaefer model:

$$\frac{dB_1}{dt} = G(B_1) - \sum_{i=1}^{N_1} Y_i, \tag{1}$$

$$\frac{dB_2}{dt} = G(B_2) - \sum_{j=1}^{N_2} Y_j, \tag{2}$$

Stock 1 is harvested by N_1 fishers and stock 2 by N_2 fishers. Growth of stock is given by a logistic growth function,

$$G(B_1) = rB_1(1 - B_1/K_1), \tag{3}$$

$$G(B_2) = rB_2(1 - B_2/K_2), \tag{4}$$

where r is the intrinsic growth rate of fish while K_1 and K_2 are the carrying capacities. We have production functions (yield for fisher i on lake 1 = Y_i) of the Gordon-Schaefer type,

$$Y_i = qf_i B_1 \tag{5}$$

$$Y_j = qf_j B_2 \tag{6}$$

Here B_1 and B_2 are the stocks, f_i and f_j are fishing efforts and q is catchability coefficient that is equal for all fishers.

The steady state stocks of the two lakes (B_1 and B_2) are derived by using Eqs. 1–6 when harvest equals growth

$$B_1 = \frac{K_1}{r} \left(r - q \sum_{i=1}^{N_1} f_i \right), \tag{7}$$

$$B_2 = \frac{K_2}{r} \left(r - q \sum_{j=1}^{N_2} f_j \right), \tag{8}$$

We see that for each level of fishing effort there is a corresponding steady state stock level that can be sustained. The interlocked stock is the sum of the steady state stocks of the two lakes $B_{tot} = B_1 + B_2$.

The model we use assumes that the fishers have zero discount rate and they compete against one another. Relaxing the zero discount rate assumption would not have any qualitative impact on our main results. However, a dynamic model with positive discount rates would have an impact on stock dynamics, thus creating a possibility for extinction or serious depletion of the stock.

Given the production function (Eqs. 5–6), stock restriction (Eqs. 7–8) and the behaviour of the other fishers (Eqs. 7–8), the fishers maximize their profits P in each lake, as follows:

$$\text{Max } P_1 = \max (pY_i - C_1 f_i)$$

$$\text{Max } P_2 = \max (pY_j - C_2 f_j)$$

In these objective functions p = price. Solving these functions gives an optimal fishing effort for each fisher as a function of the other fishers (*see* appendix). Let us next discuss how these functions are solved to yield the equilibrium of the game.

Symmetric equilibrium

Symmetric equilibrium is such that fishers in both lakes have the same fishing costs ($C_1 = C_2 = C$). The equilibrium fishing effort may still vary between the lakes as the number of fishers may be different. Within a lake all fishers have the same equilibrium fishing effort. In the case of N_1 and N_2 fishermen this maximisation yields the following non-cooperative equilibrium fishing efforts (*see* Appendix for detailed derivation):

$$f_i^{\text{Nash}} = \frac{r}{(N_1 + 1)q} (1 - D_1) \tag{9}$$

$$f_j^{\text{Nash}} = \frac{r}{(N_2 + 1)q} (1 - D_2) \tag{10}$$

Here $D_1 = C/pqK_1$, $D_2 = C/pqK_2$ and the interlocked effort (sum of fishing efforts) is equal to $f_{tot} = N_1 f_i^{\text{Nash}} + N_2 f_j^{\text{Nash}}$. The equilibrium fishing effort depends on the number of fishers and on the biological and economic parameters. For example, the equilibrium fishing effort decreases if fishing costs increase.

Asymmetric equilibrium

Asymmetric equilibrium is typically such that there are only more cost efficient fishers harvesting from one lake (lake 1), while the other lake (lake 2) is a mixture of more and less cost efficient fishers. Within lake 2 the equilibrium fishing efforts of the more cost efficient fishers are thus higher than the equilibrium efforts of the less efficient fishers, whereas within lake 1 all fishers have the same equilibrium fishing effort.

If one or several lake 1 (high K) fishers access lake 2 (low K), there exists a symmetric

equilibrium (Eqs. 9–10) for lake 1 and possibly an asymmetric equilibrium for lake 2. The lake 2 asymmetric equilibrium is given as (*see* Appendix for detailed derivation):

$$f_j^{j\text{Nash}} = - \sum_{k=1}^{N_{1\text{entry}}-1} \frac{r}{(N_2 + N_{1\text{entry}} + 1)} (1 - D_i^k) - \sum_{m=1}^{N_2-1} \frac{r}{(N_2 + N_{1\text{entry}} + 1)} (1 - D_j^m) + \frac{(N_2 + N_{1\text{entry}})r}{(N_2 + N_{1\text{entry}} + 1)q} (1 - D_j^j) \quad (11)$$

The equilibrium effort depends on the number of fishers on the small lake and the number of fishers entering from the large lake. If the fishing costs of the competitors of fisher *j* (entrants or existing fishers) increase, fisher *j* finds it optimal to increase his fishing effort due to better competitive advantage over his competitors.

Reconstruction of the interlocked fishing district

In order to test the interlocked use approach an interlocked fishing district was reconstructed from the YPUE data from vendace seine fishing from 1972–1993. The three lakes represent different sizes (3200, 7600 and 23 700 ha) within a distance of 100 kilometres. The data consist of commercial winter-seine fishing and are collected by the Rural Advisory Center of Oulu, mainly by structured interviews.

Two main questions asked in the analyses were: How much lower is the variation in interlocked YPUE than in YPUE on each lake, and what is the benefit if the constant interlocked fishing effort (sum of lake-specific efforts) were allocated only to the lakes with highest stock densities in each year?

Results

Symmetric unit effort costs

In the current section, the fishers were supposed to have similar unit effort cost, that is,

we assumed symmetry. Three simulations were carried out (case 1 to 3). Our simulations demonstrate how many of the fishers will find it optimal to travel to lake 1 with cost $A_2 = 1$, (Table 1).

The first simulation assumed no mobility, and produced a total yield of 24.76. In simulation 2, fishers had a possibility to change to the other lake. It is profitable for a more productive lake fisher to choose the less productive lake if more profits can be obtained after subtracting the mobility cost.

$$pqf_j(N_2 + 1)B_2(N_2 + 1) - cf_j(N_2 + 1) - A1 > pqf_i(N_1)B_1(N_1) - cf_i(N_1) \quad (12)$$

Under this equilibrium condition, movement to the new lake should be profitable even after the number of fishers increases by one ($N_1 + 1$) (Table 1). The interlocked equilibrium is a combination of f_i, f_j, N_1 and N_2 . The fishers’ total profits and total yield were increased when mobility of fishers was made possible. On the other hand the total stock size diminished in the non-cooperative equilibrium.

In the third simulation, the optimal number of fishers in both lakes was sought. The total profits and stock size were again used as indicators of the profitability.

Table 1. — **A:** Simulation 1, no mobility. — **B:** Simulation 2, free mobility. — **C:** Simulation 3, economically optimal allocation of fishers (max. total stock and total profits). $K_1 = 100$ and $K_2 = 50$. Cost of travelling from lake 1 to lake 2 is $A_1 = 0.05$. Further, $p = 1$; $r = 0.8$; $q = 0.8$; $C = 12$. Note that profits P_1 and P_2 are individual fishers’ profits and these are multiplied by number of fishers to obtain the interlocked profit (total profit).

| | A | B | C |
|--------------------------|----------|----------|----------|
| N_1 | 8 | 7 | 1 |
| N_2 | 3 | 4 | 10 |
| B_1 | 39.56 | 40.50 | 66.00 |
| B_2 | 29.00 | 27.60 | 24.55 |
| B_{tot} | 68.56 | 68.10 | 90.55 |
| P_1 | 0.71 | 0.90 | 14.45 |
| P_2 (from lake 1)/ N | | 0.73 | 0.11 |
| P_2 | 1.23 | 0.78 | 0.16 |
| Total profit | 9.37 | 9.37 | 15.70 |
| $\sum Y_i$ | 14.78 | 15.25 | 19.55 |
| $\sum Y_j$ | 9.98 | 9.86 | 9.26 |
| Total yield | 24.76 | 25.11 | 28.81 |

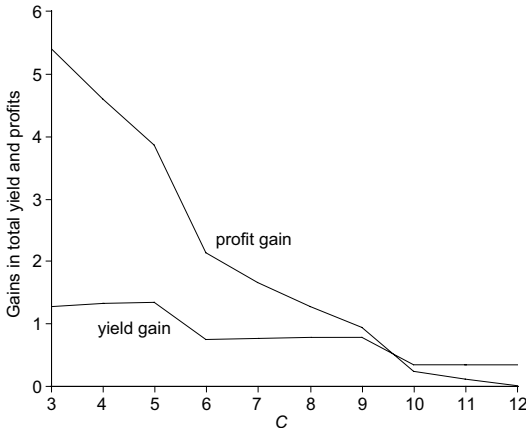


Fig. 1. Gain in total profits and yield from free mobility, when a new fisher enters the less productive lake, as a function of C (= cost of more efficient lake 1 fishers). For less efficient lake 2 fishers $C = 12$.

Not surprisingly, the optimal structure of harvesting was such that the more productive lake was given monopoly rights. This follows because mobility costs were low. Further, since the total profits increased as a consequence of introducing mobility of fishers, it could be possible to design compensation schemes for those fishers who are worse off than in the case of no mobility. Total harvests were maximised in the current example with $N_1 = 2$ and $N_2 = 9$.

Asymmetric unit effort costs

In the current section, the fishers were supposed to be asymmetric with respect to unit effort cost (see Quinn & Ruseski 2001). Thus, the vector of the unit costs C varies for lake 1 fishers and $C = 12$ (constant) for lake 2 fishers.

In the asymmetric case, the non-cooperative equilibrium further increases overall profits and harvests (Fig. 1). The lower the unit cost of harvesting for lake 1 fishers the higher the gain in total profits. This is because the more efficient (low-cost) lake 1 fishers drive out the less efficient lake 2 fishers. Yield gain may be decreasing with decreasing costs until an additional lake 1 fisher enters lake 2 and as a consequence harvest gain jumps upwards. For example, from $C = 9$ to $C = 6$ the yield gain is decreasing since the equilibrium number of fishers is unchanged ($N_1 = 6$ and $N_1 = 5$). However, if $C = 5$, then an additional

large-lake fisher enters the small lake and consequently the yield gain jumps upwards. Figure 1 also shows how the total gain in yield develops as a function of large lake unit cost of effort. There is also a negative, but non-monotonic, relationship between harvesting cost for the more efficient lake 1 fishers and the gain in total yield.

It is important to note that our simulation example above describes theoretically only some specific vendace lakes and lake systems (out of the numerous combinations of multiple lakes/stocks that can be regarded as interlocked) in which the biological and socio-economic conditions prove favourable. For some groups of lakes it might well be that introducing fishers mobility would decrease overall profits and harvests in equilibrium. In fact in our model it is fairly easy to find such examples.

Reconstruction of the interlocked fishing district

The following results show how an interlocked fishing district could affect the socio-economics of the fishery in practice, and outline implications for interlocked management. During the time from which the reconstruction-data derive, the fishery in Kuusamo has changed in many respects. The total number of commercial fishers has grown from about 10 to 50 (commercial fishing — the winter seine technique — was first introduced to Kuusamo in 1970–1971, prior to that the fishery was mainly subsistence fishing with gillnets). Due to the relatively small distances between the lakes (max. 100 km, up to two hours land-trip) some use of more than one vendace stock has taken place, but usually due to the locally-centered licences and lack of co-management of multi-resource areas the potentials of both biological and socio-economic subsystems remain unclear (Salmi & Huusko 1995a).

Along with the increase of fishers and the development of fishing techniques the fishing intensity has grown especially in the small lake whereas in the largest lake the intensity has remained low (Salmi & Huusko 1995a). In relation to the productive potential of vendace stocks this implies different types of utilisation of the resource: geographically smaller resources have

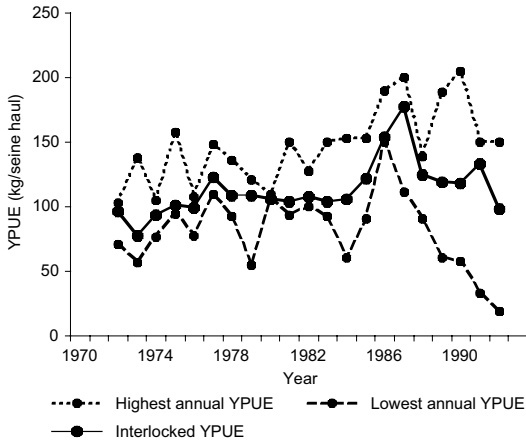


Fig. 2. Interannual variation in the interlocked YPUE and the highest and lowest annual YPUE of the three lakes.

been exploited closer to the fringe of sustainability whereas in the larger resources a considerable part of the potential yield seemed to remain unused. In the yield-data model covering 21 years, the YPUE in the interlocked fishing district was at worst 31% below the average of the whole period (and at best 56% above it), whereas in one individual stock it went 80% below the average. The inter-annual variation in the interlocked vendace stock (area-weighted mean of the 3 lakes) was considerably lower than the inter-annual variation in the separate lakes (Fig. 2). The coefficients of variation (CV) in the lake-specific YPUE varied from 26% to 45% and were significantly higher than the CV of the interlocked YPUE (19%).

According to the model, considerable stability in yield could be obtained simply by reallocating present fishing efforts more evenly among the fishers, without changing fishing efforts on individual stocks (Fig. 2). In the following section we look at the same model with a simple application of interlocked management.

The effect of mobility

If we assume the lakes in this model are managed as an interlocked fishing district, in a simple form fishing was closed in the lake with the lowest YPUE in each year and the constant interlocked fishing effort (sum of lake-specific

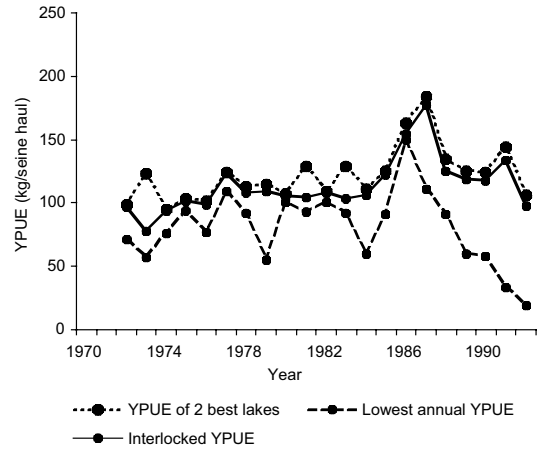


Fig. 3. The interlocked YPUE (of all 3 lakes) and the interlocked YPUE if fishing was closed in the lake of the lowest YPUE in each year, and fishing effort of this lake shifted to the other two lakes (YPUE of 2 best lakes).

efforts) was allocated to the lakes with the highest stock densities. Then the interlocked YPUE increased by 8% (Fig. 3). It was assumed for simplicity that the allocation of the fishing effort had no effect on the fish stocks in the lakes under fishing or conservation and the unused potential on the two productive lakes could sustain the increased fishing effort with the same average YPUE. It is noteworthy that the YPUEs used in the model include only commercial fishing. The other part of the utilization consists of subsistence and recreational gill-net fishing.

If we assume that the management goal of this interlocked fishing district is “no YPUEs smaller than 80% of the long term average in the area”, in this reconstruction it would mean that in 10 out of 21 years one of the stocks should be conserved. Management also needs to find the most suitable lake(s) for this fishing effort out of the two other lakes. If, in this example, areas with YPUE at least 20% higher than average are designated as good for increased fishing effort, lakes available for increased fishing are found in 15 years out of 21. In six years abundance and depletion coincide in different parts of the interlocked stock. In four years there are one or two areas of depletion but none with an abundant stock, and in nine years there are one or more abundant stock areas and none with depletion. Finally there are two years when YPUE from all the three stocks are within 20% of the average.

Discussion

Interlocked use is a theoretical approach in looking for solutions to the problems of the inland fisheries system and thereby improving its performance. In practice, it aims at optimal allocation of fishing effort following the spatial dynamics of the resource. One of the main consequences would be more constant flow of income for the fishers, both within a year and between years.

The results of the economic model show that the management of the interlocked fishery, in particular encouraging fishers mobility, is on certain terms in a key position in order to obtain higher sustainable economic benefits from the fishery. We have highlighted several important factors that affect the equilibrium of the fishery. These factors include mobility costs, unit harvesting costs and the number of fishers. In successful management, all these factors should be taken into account.

This sets new requirements for decision-making. More constant fish flow could be achieved by allowing fishing enterprises to move more freely between several lakes and exploit the stocks according to their biological status. The interlocked stock (sum of stocks under exploitation in a given interlocked fishing district) would have to be monitored frequently and target fishing effort would be set for each stock. In certain lakes, fishing could be restricted when the stock declines to the risk level. This, or related operations, could increase the capability of fishing enterprises to avoid the risks connected to the use of natural resources and create tools for improving the sustainable use of fish resources.

Both basic types of interlocked use of the stocks described in the yield data-model (reallocation of total yield among fishers with no other management measures or preserving the weakest stock and shifting fishing effort to the other stocks) and their more complex applications would require either cooperation of fishers or rather strict means of regulation, or both. The first type, reallocation of total yield among the fishers within an interlocked fishing district is hardly a realistic alternative because reliable yield-data is usually obtained some time after the fishing season, and because of variation in

individual fishing efforts. The economic model shows that even in the absence of cooperation, interlocked use may be economically beneficial to the fishers.

The second type of interlocked use would require mobility of most, but not necessarily all, fishers. In practice it would be necessary to look for solutions where some fishers use the interlocked fishing district at their present areas, and those capable of mobility would use several areas within the district. Here the (maximum) fishing effort on each individual stock would be determined by a management body before and/or during each fishing season. In addition to other interest groups, this body could include fishers, and some degree of cooperation between them could occur. If no fishers were involved, management could set the limits for maximum fishing effort and put the licenses out for competitive tender. As commercial fishing in many areas is opposed by other interest groups, a predetermined limit to the number of fishers within the area would be needed in any case. Preserving one or more stocks completely for a limited period may not be necessary in order to restore the stocks. In some situations the stock can sustain limited fishing effort during a low-stock period. Thus it is possible in decision-making to apply different degrees of mobility of fishers depending on the biological condition of the individual stocks and on the personal situations of the fishers involved.

According to the yield-data model we can outline five basic situations for management and reallocating fishing effort within an interlocked stock area:

1. Depletion, no good areas — How to cope with low stocks?
2. Depletion, few good areas — How high can the increased fishing effort be?
3. Depletion, several good areas — How to allocate the fishing effort spatially?
4. All stocks near long term average — No need for mobility.
5. No depletion, one or more abundant stocks — How to share abundance?

In all cases with depletion, the possibility to move should apply to the fishers in areas with lowest stocks. In situations 1 and 4, the fishery

may adjust to the condition with no mobility. In 2 there is pressure for very high fishing effort on a small part of the interlocked stock area, which also demands extended adaptation from the other users. In 3 the key question is how the management — owners and fishers — succeed in distributing the fishing effort according to the various biological states of several abundant stocks, and in 5 should the interlocked stock area work as a distributor of abundance in addition to being an ‘insurance’ for depletion?

Previous studies have indicated that with fewer restrictions on commercial fishing, many of the fish resources (new lakes or new areas on present lakes) near the areas of present commercial fishery would be taken into use (Niittykangas *et al.* 1993, Salmi & Salmi 1997). In other words, many of the present fishers wish to expand their fishing grounds to areas that are known to be suitable for vendace fishing. Therefore the fishing effort on presently strongly exploited areas could be lowered, and ecological sustainability could be reached at present or even somewhat higher fishing intensity. This implies that, provided the number of fishers, or total fishing effort within any designated area of interlocked use could be limited to the present level, the main questions of establishing and running an interlocked fishing district lie in the political-administrative and socio-economic subsystems.

Political-administrative subsystem

In the political-administrative subsystem, commercial fishing is restricted by private joint ownership of fishing rights. Inland lakes are divided into several small and rather independently operating statutory shareholders associations. Until the beginning of the year 2001 shareholders association (*osakaskunta*) was known as fishery association (*kalastuskunta*). The change was due to a new law, in which management of joint private ownership of water and land areas were combined. This did not cause any major changes in the practical functions of the associations. Their attitude towards commercial fishing is variable and often bears the imprint of the recreational and subsistence fishers’ view, the latter constituting, in most cases, the main

owner groups. Statutory shareholders associations share concern for the state of the utilized fish stocks, but their management policies, often lacking cooperation with other shareholders associations, often hinder unified management measures (Muje *et al.* 2001). The successful operation of a commercial fisher is usually dependent on getting fishing licenses for the fishing grounds of several adjacent shareholders associations, which has been difficult to put into action. Getting licences for several lakes in order to decrease the uncertainty of yield from a single lake, has turned out to be almost impossible, especially concerning trawling.

The licencing policy of the shareholders associations, in terms of fishing intensity, also seems to allocate fishing effort unevenly in lakes of different sizes (and in different parts of lakes). Lakes with more shareholders associations per area (typically smaller lakes) seem to be a target of more intense fishing than larger lakes. In practise this binds together the issues of ecological and socio-economic sustainability. Implementing land-estate management into lake management in shareholders associations has resulted in various levels of “traditional” useage per area in different lakes, or even different parts of lakes.

The ownership-based management system has developed to a point where it offers a forum for most relevant interest groups to participate in decision-making (in shareholders associations and thereby in fisheries regions), with the exception of environmental organisations and actors that are dependent on commercial inland fishing (fish processing and trade). On the other hand, through fragmentation of management units, the system causes difficulties in taking advantage of multiple fish stocks. In other words, it seems that in those processes which have enhanced community and institutional sustainability, ecological and socio-economic sustainability have advanced little.

In the Finnish context of private water ownership, interlocked use would require wide acceptance among local owners and at least partial cooperation of the fishers, in order to facilitate effective flow of local and scientific information on the stocks, and thereby sustainable fishery. The key issue in the political-administrative subsystem is the establishment of an interlocked

fishing district in the context of the present institutional structure: management system, legislation and ownership.

Empirical questions concerning the establishment of an interlocked fishing district are what are its geographical limits set by the views and needs of the main interest groups? With fishers this relates to the willingness and means to move, and with water-owners to the willingness for cooperation and improving conditions for local livelihoods. From the fishery authorities establishing an interlocked fishing district requires openness to solutions of scales that may differ from the present regions, and sensitivity to regional differences in the needs of interest groups.

Biological subsystem

An interlocked fishing district requires two kinds of information about the biological subsystem. Firstly, also concerning the founding of the system, what are the geographical limits of the interlocked fishing district set by the dynamics of vendace stocks? This will be studied further by yield data models from 1–2 other areas, and with more lakes in some examples (e.g. Kuusamo, Saimaa).

Secondly, concerning the regulation of fishing effort within the district, how do fishing restrictions affect the stock of a lake? The assumption in the yield-data model is that the fishing has only marginal effect. In practice, this could be true due to the highly unpredictable inter-annual variability in recruitment (Karjalainen *et al.* 2000), except in the case of very high fishing intensity.

In this context a potentially important factor is the spatial scale of synchrony of Finnish vendace population fluctuation, and its anisotropic structure (Marjomäki *et al.* 2004). Considering the abundance of lakes in many regions of Finland, this suggests that the variation reducing effect of population dynamics can be achieved in a number of different regions (more effectively in north–south direction) and within a relatively small area. This bears great significance considering the political–administrative subsystem. The utilization of the vendace stocks has so far failed to exhibit two basic features of interlocked use:

taking the existing stock potential in a limited number of lakes into use to achieve a more stable biological resource-base by the fishing potential of local fishers.

Also information on the effect of increased fishing effort on the stock dynamics is needed to provide the management body with adequate information to be used in regulation. At this point the biological subsystem (ecological sustainability) has an important link to the political-administrative and socio-economic subsystem (socio-economic and community sustainability).

Socio-economic subsystem

Due to the extensive geographical scale of lake fisheries and the need to adjust fishing effort during each season, scientific knowledge on the state of the stocks can only offer a partial solution to the question of regulation. The local knowledge of the fishers (fishing experience based information on the state of stocks, response to increased fishing) will be needed in order to have *adequate knowledge* on which to base the system. The relation of local and scientific knowledge in the regulation is a matter of negotiations between interest groups in the process of forming an interlocked fishing district. The likely outcome of giving local knowledge a formal status in the system is increased acceptance of the system by local interest groups (Pinkerton 1994).

In addition to the issue of adequate information for regulation, the socio-economic questions relate mainly to the interest groups' ability to adjust to the system. Interlocked use requires increased mobility. Important questions are: how high the real mobility costs are, how mobility costs limit the geographical scale of an interlocked fishing district and how stabilizing the supply of fish will affect its price and the income of fishers. Another important question is the possible need for compensation to other interest groups for occasionally increasing commercial fishing.

Future work involves using real data on the Finnish vendace fishery to study the problem in detail. A dynamic age-structured model with several lakes will be developed. From the biological

point of view this would also include a stochastic population dynamics model accompanied by possible synchrony between the lakes. From an economic point of view we know that the price is a function of yield and supply, and additionally fishing costs should be estimated. The possible cooperative behaviour of fishers, in particular in the case of asymmetric fishers (varying fishing cost-efficiency) should be taken into account.

The models show that ecological and socio-economic sustainability in Finnish vendace fisheries could be improved applying the approach of interlocked use. The socio-economic, political-administrative and biological subsystems will be studied further in order to find appropriate scales and practices for management of interlocked fishing districts on socio-culturally and biologically different lake areas.

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Appendix

Derivation of Eq. 9: Symmetric equilibrium fishing efforts in lake 1

$$\max P_1 = pqf_i \left(K_1 - \frac{K_1 q f_i}{r} - \frac{K_1 q \sum_{j \neq i}^{N_1-1} f_j}{r} \right) - c f_i$$

$$\text{FOC: } pqK_1 - \frac{2pq^2 f_i K_1}{r} - \frac{pq^2 K_1 \sum_{j \neq i}^{N_1-1} f_j}{r} - c = 0$$

Divide both sides by pqK and note $D_1 = c/pqK_1$.

$$1 - \frac{2qf_i}{r} - \frac{q \sum_{j \neq i}^{N_1-1} f_j}{r} - D_1 = 0$$

Applying symmetry and multiplying by r :

$$2qf_i + q(N_1 - 1)f_j = r(1 - D_1)2qf_i$$

From this expression it is possible to calculate the equilibrium fishing efforts:

$$f_i^{\text{Nash}} = \frac{r}{q(N_1 + 1)}(1 - D_1)$$

Note that an identical procedure yields also the equilibrium fishing effort of lake 2 fishers (Eq. 10).

Derivation of Eq. 11: Asymmetric equilibrium fishing efforts in lake 2

The asymmetric equilibrium is constructed as follows. We first calculate the equilibrium for two asymmetric players, and after that generalise the result for n players.

The maximisation problem is now defined for only 2 fishers that are asymmetric with respect to their fishing costs, and additionally we now have carrying capacity of lake 2 (K_2) and fishing efforts in lake 2 (f_j):

$$\max P_1 = pqf_j^1 \left(K_2 - \frac{K_2 q f_j^1}{r} - \frac{K_2 q f_j^2}{r} \right) - c_1 f_j^1$$

$$FOC: pqK_2 - \frac{2pq^2 f_j^1 K_2}{r} - \frac{pq^2 K_2 f_j^2}{r} - c_1 = 0$$

Divide both sides by pqK_2 and note $D_j^1 = c_1/pqK_2$.

$$1 - \frac{2qf_j^1}{r} - \frac{qf_j^2}{r} - D_j^1 = 0$$

From the above expression we can calculate the reaction function of fisher 1, that is, the optimal response of fisher 1 as a function of fishing effort of fisher 2.

$$f_j^1 = \frac{r}{2q} (1 - D_j^1) - \frac{f_j^2}{2}$$

Similarly we have the reaction function of fisher 2:

$$f_j^2 = \frac{r}{2q} (1 - D_j^2) - \frac{f_j^1}{2}$$

Now we have a system of two linear equations with two variables, and thus we can solve the equilibrium fishing asymmetric fishing efforts:

$$f_j^1 = \frac{2r}{3q} (1 - D_j^1) - \frac{r}{3q} (1 - D_j^2)$$

$$f_j^2 = \frac{2r}{3q} (1 - D_j^2) - \frac{r}{3q} (1 - D_j^1)$$

Repeating the same procedure for three, four and finally n fishers generalises the result for n fishers. Note that we can also deduct the generalisation directly from the above equilibrium fishing efforts for two asymmetric fishers.

In the n fishers case the asymmetric equilibrium for fisher i is:

$$f_j^{i\text{Nash}} = - \sum_{k \neq i}^{n-1} \frac{r}{(n+1)q} (1 - D_j^k) + \frac{nr}{(n+1)q} (1 - D_j^i)$$

In lake 2 there are two types of fishers. The original fishers of lake 2, which are denoted by N_2 , and the fishers that enter lake 2 from lake 1, which are denoted by N_{entry} . Hence, the total number of fishers in lake 2 is $n = N_2 + N_{\text{entry}}$. Adding these refinements in the above expression finally yields our asymmetric equilibrium fishing efforts in lake 2:

$$\begin{aligned}
 f_j^{j\text{Nash}} = & - \sum_{k=1}^{N_{\text{entry}}-1} \frac{r}{(N_2 + N_{\text{entry}} + 1)} (1 - D_i^k) \\
 & - \sum_{m=1}^{N_2-1} \frac{r}{(N_2 + N_{\text{entry}} + 1)} (1 - D_j^m) \\
 & + \frac{(N_2 + N_{\text{entry}})r}{(N_2 + N_{\text{entry}} + 1)q} (1 - D_j^j)
 \end{aligned}$$

Note that index k corresponds to the number of entrants to lake 2, and index m the number of original fishers.