Kari Saulamo and Gunnar Thoresson †

Management of Pikeperch Migrating over Management Areas in a Baltic Archipelago Area

Pikeperch *Sander lucioperca* (L.) were tagged in an area where ten small independent management units regulate fisheries, in order to analyze the relevance of migrations for the management. A total of 465 fishes were tagged in connection with the spawning migration. The number of recaptures was 96. The distribution of recaptures between areas and that of total catches, estimated from questionnaire to housholds and, individuals in the survey area, were correlated. The comparison of tagging and recapture dates showed that the same pikeperch migrated to the spawning areas at the same time in two subsequent years, indicating the existence of individual spawning behavior. A modified yield/recruit-model demonstrated that in situations where the dispersal area of a pikeperch stock overlaps with several management areas, the risk of overfishing is very high. Management of this kind of fisheries needs cooperation between units as well as sound data on the movements of pikeperch to define the effects of fishing regulations.

INTRODUCTION

Many economically important fish stocks have collapsed as a consequence of high fishing pressure and inefficient fisheries management (1–5). Management failures have often been seen as a result of insufficient knowledge of the ecology of the species managed or of ignoring this knowledge (1). Centralized decision making and disregard of the social aspects of fisheries have also been seen as a reason for unsuccessful management (3, 5, 6). Although most major collapses reported have taken place in open access high seas fisheries, economically important fish stocks can be overexploited also in nationally managed coastal waters. In addition, conflicting interests between different activities in coastal areas (e.g. fisheries, land use, agriculture, transports, industry and recreation) require consideration of not only biological but also economical, social and cultural factors in management. Delegating decision making to the local level together with integrating the management between different sectors have been established as a strategy for revering the negative development of the fish stocks in the coastal waters of Europe (7).

In the Baltic archipelagos of Finland and Sweden, local management systems exist which are based on private ownership of fishing rights. The owners are organized in associations mostly corresponding to old administrative units, i.e. villages and municipalities. These units are often relatively small and share the same resource, i.e. fish stock. In a biological sense, management would be most effective if each individual stock could be managed separately (1) and a management area covered the whole life cycle, i.e. spawning, feeding and wintering areas.

Pikeperch *Sander lucioperca* (L.) is a valuable species both in commercial and recreational fisheries, and in many areas, its stocks are overexploited (8–10). Management of pikeperch fisheries consists typically of gear restrictions, minimum mesh sizes, size limits, and prohibiting fishing during the spawning season and/or spawning areas. Sufficient knowledge of the dispersal areas and movements of stocks is crucial for successful fisheries management (11). This is especially important in cases where the dispersal area of a stock overlaps several management areas. If the number of management units is large, competition for catches between units can increase the probability of overexploitation. Improved knowledge of spatial dynamics of fish stocks contributes to better management by providing an instrument for assessing the effects of management actions.

Pikeperch prefers to live in open water (12) and can migrate up to 300 km (13). Usually, migrations are considerably shorter the 300 km; typically less than 10 km (14). Migrations depend on the morphometry of the coast and especially the location and quality of spawning areas (14, 15). Migration to spawning areas, typically shallow bays and inlets, starts about one month prior to the actual spawning (15–17). In the southern Baltic Sea, the spawning takes place mostly in April–May (16, 18) and in the northern Baltic and in the Gulf of Finland in May–June (9). After spawning, the pikeperch move to the feeding areas, typically located close to the spawning areas. In autumn, they usually leave shallow waters, and their winter habitats are in deeper waters (19).

The aim of this study was to analyze the management implications of migrations for a situation where several small independent management units exploit the same pikeperch stock. In such an area, this was done by comparing the spatial distribution of recaptures from a tagging experiment with that of the total catches as derived from an inquiry. Furthermore, a modified yield/recruit–model analysis was performed to find the most rational fishing strategy for a single management unit with regard to different degrees of stationariness of the pikeperch. The existence of possible individual spawning behavior was also studied, comparing tagging day with recapture day in subsequent years.

MATERIAL AND METHODS

Study Area

The study area, close to the town of Östhammar, on the eastern coast of Sweden (60°N, 18°E) in the Baltic Sea, is characterized by a sheltered archipelago (Fig.1). In the inner, western parts, littoral areas are typically edged with dense reed (*Phragmites australis*) belts. The underwater vegetation is dominated by *Potamogeton* sp., *Myriophyllum* sp., *Chara* sp., and *Najas marina* (20). The average depth ranges from 2–4 m in the west (Granfjärden) to 10–20 m in the central basin (Galtfjärden). Common fish species are roach *Rutilus rutilus* (L.), bream *Abramis brama* (L.), white bream *Abramis bjoerkna* (L.),

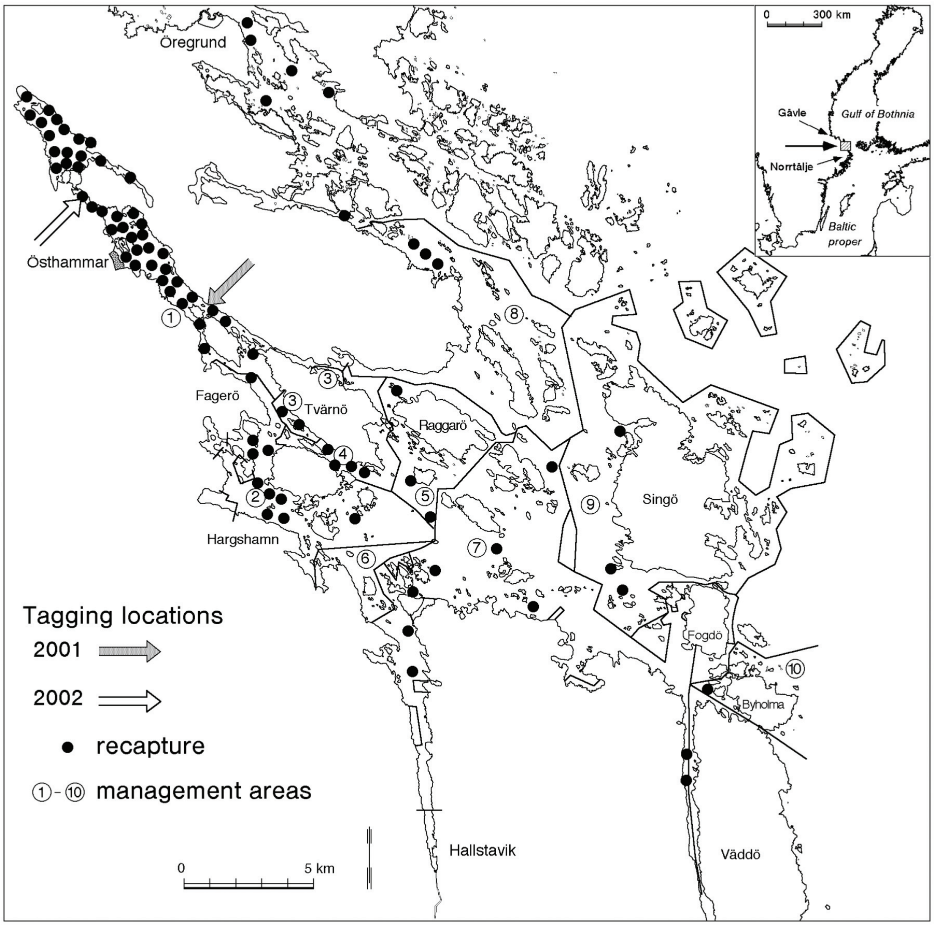

Figure 1. The study area, tagging locations, management units (1–10) and the location of recaptures caught in 2001–2003. Two recaptures were caught outside the map.

bleak *Alburnus alburnus* (L.), ruffe *Gymnocephalus cernuus* (L.), pike *Esox lucius* L., perch *Perca fluviatilis* L., smelt *Osmerus eperlanus* (L.), herring *Clupea harengus* L. and pikeperch (20). The salinity in the area is about 3‰. Pikeperch is the most valued species in the fisheries, gillnetting being the dominant fishing method. Total pikeperch yield in 2001 was ca. 30 tonnes. Catch distribution beeing for household (mostly subsistence gillnet) fishing 18 tonnes, rodfishing 4 tonnes, and professional fishing (five fishermen) 8 tonnes (G. Thoresson, unpubl. data). The fishery is managed by ten independent management areas (21) of which the westernmost (area 1; Fig. 1) covers the main spawning grounds of pikeperch.

Tagging

Pikeperch were caught with one-directional fyke nets and gillnets. In 2001, also small two directional fyke nets were located in Granfjärden (tagged N = 22). One large fyke net was placed in a sound outside the Östhammarsfjärden basin and was set to catch only fish swimming inward (N = 170) (Fig. 1). Gillnetting took place both in Granfjärden and Östhammarsfjärden (N = 20). In 2001, taggings started on 9 May and ended on 1 July. In 2002, the fishing was performed with two one-directional fyke nets, one catching fish swimming inward (N = 210) and the other catching outward going fish (N = 43). These were placed in a narrow sound connecting the Granfjärden and Östhammarsfjärden basins (Fig. 1). Fishing covered the whole period of prespawning, starting 3 April and ending 20 June. Total number of tagged fish was 212 in 2001 and 253 in 2002. The average length of the tagged pikeperch was 43.8 cm in 2001 (range 22–79 cm) and 46.7 cm (range 21–85 cm) in 2002. Tagging was done with nylon dart tags (22). When tagged, the fish were measured for length (total length), tagged and released immediately at the place of capture. Tags from recaptured pikeperch were sent to the Institute of Coastal Research with date, gear and catch location information. A reward was paid for returned tags.

Inquiry

The target group of the inquiry comprised households or individuals connected to the survey area and living in the municipalities of Östhammar and Norrtälje, in which the survey area is situated. The inquiry was sent to water owners, other estate owners, holders of boat mooring places, fishing club members and occasional visitors to the area. In February 2002, 1995 inquiries were posted, of which 1443 (72%) were returned. The respondents were assumed to represent the total population of 13 000 households, for fishery behavior and catch rate (G. Thoresson, unpubl. data). The total catch estimates describe the fishery in the year 2001.

Data Analysis

For individual spawning behavior, tagging data from 2002 and recaptures from 2003 were used with tagging and recapture occurring in the same area. The aim was to investigate whether a correlation exists between tagging dates and recapture dates in the following year, indicating a non-random return to the spawning area. This was studied using Spearman correlation analysis. Comparison of spatial distribution of recaptures with total catches based on the inquiry was performed with linear (Pearson) correlation. Pikeperch recaptured sooner than one month after tagging were excluded from the statistical analysis. Statistical analyzes were performed with s-plus software (23).

Management Strategy Analysis

In order to analyze the effects of the different fishing strategies in an individual management area, a yield per recruit (Y/R) analysis was performed. Y/R analysis is based on growth data and an assumption of natural mortality (24, 25). Here, the model was modified by splitting fishing mortality to one representing the fishing pressure in the area of interest and one representing the other areas. Further, different degrees of stationariness of pikeperch were included in the model using the variable number of months each year the fish stay in the area of interest. Three time periods were used: nine months (July–March), six months (October–March) and three months (April–June). In the first case, the fish leave the area only during spawning, in the second they spend the spawning and growth season outside the area, and in the third they only spawn in the area.

The model was based on the following equations:

$$Y_{t,a} = \omega_t * \frac{F_{t,A}}{F_{t,A} + F_{t,B} + M_t} * N_{t,a} * (1 - e^{-(F_{t,A}+F_{t,B}+M_t)}) * W_a \quad \text{Eq. 1}$$

$$N_{t+1,a} = N_{t,a} * e^{-(F_{t,A}+F_{t,B}+M)} \quad \text{Eq. 2}$$

Where:

$Y_{t,a}$ = yield from age-group a in month t

ω_t = location of pikeperch in month t ($\omega = 1$ if fish in A in month t, otherwise $\omega = 0$)

$N_{t,a}$ = number of fish in age-group a in month t

$N_{t+1,a}$ = number of fish in age-group a in month t +1. (If t +1 = 13; t = 1, a = a + 1)

$F_{t,A}$ = monthly fishing mortality in area A

$F_{t,B}$ = monthly fishing mortality in other areas

M_t = monthly natural mortality

W_a = average weight of fish in age-group a

From equations 1 and 2, the total yield for age-groups 2 to 20 (pikeperch < 2 years old are not recruited to the fishery) in area A was calculated by summing:

$$Y_{tot,A} = \sum_{t=1}^{12} \sum_{a=2}^{20} Y_{t,a} \quad \text{Eq. 3}$$

Total yields were then standardized to percent of the maximum yield to obtain easily comparable results. Present total mortality was estimated from age-groups 3 to 9 from experimental gillnet fishings in the Galtfjärden basin in the years 1997–2001 (K. Saulamo, unpubl. data). These were done with gillnet series consisting of nets with mesh sizes 25, 30, 38, 50, 60 mm (bar length) in 1997–1998 and 25, 30, 38, 45, 50, 60 mm in 1999–2001. Natural mortality was assumed to be 0.15 (8). The growth of pikeperch was estimated using the von Bertalanffy growth model from mean lengths of age groups (25), of which the weights were then calculated with length-weight relationship, based on samples from fyke net fishings in 2002.

Table 1. Recaptures in different years, excluding pikeperch recaptured sooner than one month after tagging. Totals, including those recaptuered immediately after tagging, are presented in parentheses.

Management area	2001	2002	2003	Total
1	1 (4)	15 (22)	19	**35 (45)**
2	1 (3)	5	2	**8 (10)**
3	1	1		**2**
4	1 (2)	1	1	**3 (4)**
5	1	2		**3**
6		1		**1**
7	4	5	3	**12**
8	3	1		**4**
9	2	1		**3**
10			1	**1**
Outside	3	7	1	**11**
Total	**17 (23)**	**39 (46)**	**27**	**83 (96)**

RESULTS

In total, 96 tags were recaptured, of which 85 were caught in the study area (Table 1). Of the recaptures, 70% were made in three management areas (Table 1). The furthermost recapture was caught about 140 km north from the tagging site (close to the town of Gävle) (Fig. 1.). No recaptures were reported south from the study area (Fig. 1).

Of the total 96 recaptures, 72 were caught with gillnet, seven with longline, six with rod, and for nine fish no gear were reported. The time distribution of the recaptures indicates that the catches stay relatively high from April to October, and underlines the important role of spring fishing in management area 1 (Fig. 1, Table 2). The relatively large number of recaptures in the tagging area in subsequent years shows homing to the spawning areas.

The distribution of recaptures between management areas correlated positively with the total catches, calculated from the inquiry, except for area 1, where the taggings were done (Fig. 2). The Pearson correlation coefficient was significant even with whole data set ($r = 0.67$, $df = 8$, $p = 0.035$). Excluding management area 1 led to the very strong correlation ($r = 0.93$, $df = 7$, $p = 0.0003$).

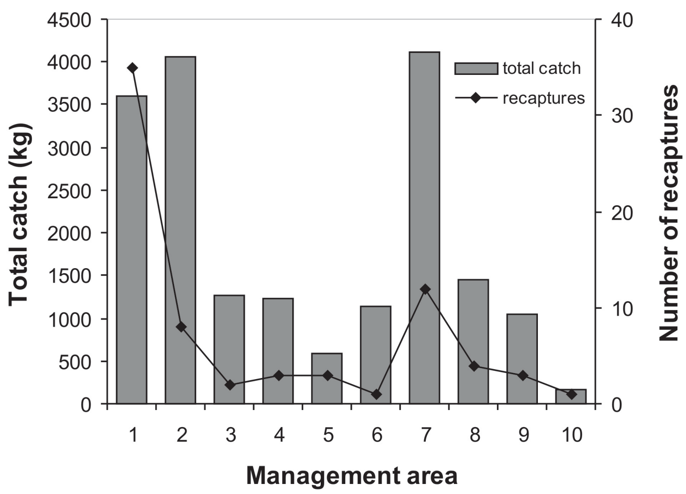

Figure 2. Total catches (based on inquiry) and recaptures (taggings) in the ten management areas.

The dates of recaptures in 2003 correlated positively with the actual tagging dates in 2002. This means that pikeperch tagged earlier were also recaptured earlier, and those tagged later were also recaptured later, during the next year (Spearman correlation $r = 0.66$; $p = 0.0237$; $n = 13$) (Fig. 3).

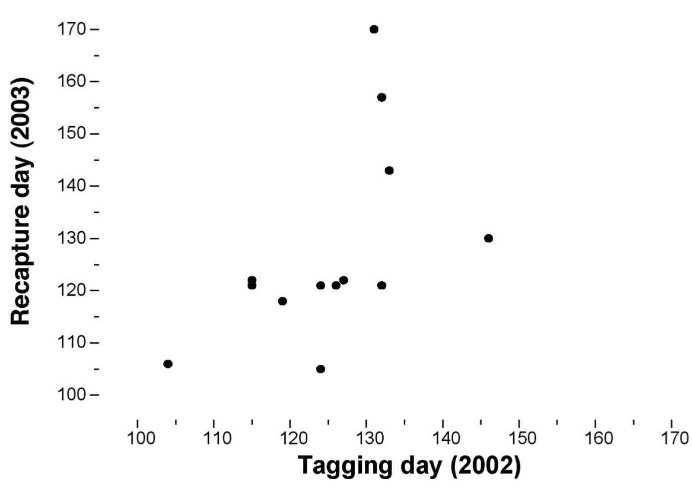

Figure 3. Tagging and recapture dates in the Östhammar management area (tagging area) for pikeperch in two subsequent years.

Table 2. Monthly distribution of recaptures between management areas excluding pikeperch recaptured sooner than one month after tagging. Totals, including those recaptured immediately after tagging are presented in parentheses. (In management area 1 one tag was received without information on recapture month).

Management area	Recapture month											Total
	1	2	3	4	5	6	7	8	9	10	11	
1	1			6 (10)	12 (14)	6 (9)	5		3	1	1	**35 (44)**
2					1	(1)	(1)	1	1	5		**8 (10)**
3									1		1	**2**
4						2 (3)		1				**3 (4)**
5						1		1	1			**3**
6					1							**1**
7				3			3	3		2	1	**12**
8							2			2		**4**
9							2	1				**3**
10								1				**1**
Outside		1	1				3	1	3	2		**11**
Total	**1**	**1**	**1**	**9 (13)**	**14 (16)**	**9 (14)**	**15 (16)**	**9**	**9**	**12**	**3**	**83 (95)**

The Y/R simulations show how fishing pressure influences the yield for different degrees of stationariness. In cases where the fish are present nine months in the area, the largest yield (F_{maxY}) is achieved with F = 0.25 (Fig 4a), whereas if they only spawn in the area (three months), the effort and hence fishing mortality needed for maximizing the yield is much higher (F = 0.8) (Fig 4c). In the case where pikeperch stay six months in the area, the fishing mortality for F_{maxY} was 0.45 (Fig 4b). This case probably mimics the typical situation in the study area best, as indicated by the distribution of recaptures between different months (Table 2). In all these situations where area A maximized its yields, F_B was 0.1, which was the lowest value used. The present F, estimated from experimental fishings was 0.95. The different shapes of the Y/R –isopleths show that if the stock is very stationary there are situations, even if the fishing pressure in the other areas is very high, when it is profitable to decrease effort. In the spawning area the most rational strategy is to increase effort unless the effort in other areas is remarkably low.

DISCUSSION

The study was based on tagging pikeperch in a spawning area during the period of spawning migrations and on the results of inquiry. The recaptures illustrate the dispersal of pikeperch from this area to several adjacent management areas after the spawning but also a homing behavior, which is known to be well developed in pikeperch (8, 13, 26–28). Therefore, even closely situated populations may be relatively isolated (8, 13, 15). The comparison of tagging and recapture dates showed that the same pikeperch migrated to the spawning areas at the same time in two subsequent years. It is too early to conclude whether such behavior is due to the fact that individual spawning behavior exists or that there are different subpopulations of pikeperch. However, these results indicate that an adequate escapement is necessary during the whole period of spawning migration and spawning to avoid possible losses of important population components.

The inquiry and the taggings gave similar results for the spatial distribution of the catches, except for the management area where the taggings were performed. In this area, the number of recaptures were high in relation to the total catches based on the inquiry. This can be partly explained by the mixing of populations in the other areas; in these other areas there are also pikeperch spawning in other inlets, whereas in the management area of Östhammar, fishing is targeted only to one population. Thus, the proportion tagged fish in the catches is probably lower in other management areas. The only city in the area (Östhammar) is located in the tagging area, and it is possible that the actual number of people fishing is higher than suggested in the inquiry sample, resulting in an underestimation of the catches. Inquiries can also overestimate catches, if those who did not answer had different behavior strategies, e.g they had not answered because they had not fished. In calculating catch estimates, their behavior is assumed to be the same as those who answered.

The Y/R model used demonstrated that in situations where the pikeperch migrates over several management areas, overfishing is difficult to avoid. The catches were largest with relatively high F in areas where the fish stays only for a short period of the year, e.g. spawning areas and those acting as a migration route. This is a consequence of a short fishing season. The most

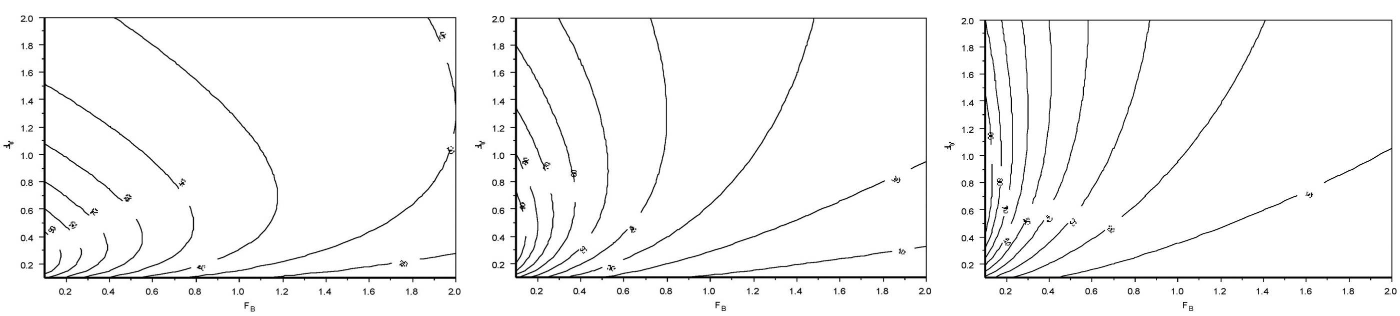

Figure 4. Y/R isopleths with three different scenarios as percent of the maximum yield the management area A can achieve. To increase yields, one has to move towards higher percent curves, moving up or down along the y-axis, with a given F (x-axis) for other areas. Present F = 0.95 (F_A,F_B)
a) High stationariness, fish stay nine months in area A (F_{Ymax} = 0.25)
a) Medium stationariness, fish stay six months in area A (F_{Ymax} = 0.4)
c) Low stationariness (only spawning area), fish are present three months in area A (F_{Ymax} = 0.8)

rational strategy for these areas is to increase the effort if other areas do so, unless the fishing mortality in the other areas is very low. On the other hand, in cases where the fish is very stationary, the largest yields are achieved with lower F. In such a fishery, the recommendable strategy is to decrease effort if neighboring areas increase it, presuming that the fishing mortality is already relatively high. By acting this way, the area minimizes its catch losses. Situations like these are very difficult for managers since they seldom can estimate if it is profitable to increase or decrease the fishing effort. Thus, in order to estimate the effects of management actions reliably, it is essential to study the spatial dynamics of the fish stock together with the F. One way to get an estimate of the spatial dynamics is to collect catch per unit effort data throughout the year in each area.

For successful management, cooperation between units is necessary. Ideally, the target overall F and how the catches generating it should be distributed between areas ought to be decided with all units involved. This is, however, seldom possible at this scale of fisheries, where managers lack the resources to do extensive population studies. If an agreement on the distribution of catches—or in practice effort—between the areas can not be reached, and one unit increases its effort, the consequence is usually that "fire is answered with fire", i.e. also the other areas increase the fishing pressure. This usually takes place even in situations where the best strategy would be to decrease the effort.

If this kind of spatial management, where the total F and thus effort is the management instrument, can not be implemented, the most suitable way of managing this type of fisheries is to regulate minimum size limit and/or minimum nets mesh size. These regulations can protect the younger age-groups and guarantees the spawning stock size. This buffers the stock from the effects of poor recruitment and temporary overfishing, thus reducing the probability of a stock collapse. An advantage of these management actions is that the effort does not need to be decreased. This is important in fisheries with a high recreational value, in which tough restrictions are difficult to enforce and can lead to economic loss for the community, if non-local fishermen can no longer obtain a fishing licence and have to move to other areas to fish. If rules for minimum fish and mesh size are adopted, they should be the same for all areas, presupposing that the importance of other target species do not differ remarkably between areas. Of course, these actions also need consensus between areas, but are easier to agree upon, as there are no tough effort restrictions preventing fishing.

The model used did not consider the relationship between spawning stock size and recruitment (S/R). Environmental factors, especially temperature during the first year of life, play a very important role in determining the year-class strength of pikeperch (29, 30), which makes the estimation of a reliable S/R relationship very difficult.

Fisheries management is being challenged worldwide (31). Different forms of co-operation where stakeholders and local actors participate in the decision making processes have been regarded as a solution for the creation of more responsible and sustainable fisheries. Defining local management units so that sustainability can be achieved and maintained is crucial for such a development. This demands information about the population structure and migration patterns, as well as the ability to discriminate the stock from adjacent populations (3). It is of great importance to consider the spatial aspects in management of pikeperch fisheries, as well as management cooperation when the same population is exploited in several management areas. Furthermore, when establishing new local management areas, information on the dispersal areas of the local populations of the most important species is crucial in avoiding situations where competition for catches can arise. In general, to achieve and maintain fisheries with high yields, the management in the entire fishing area of the population must be coordinated (32).

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Kari Saulamo is a PhD student at Department of Biological and Environmental Sciences, University of Helsinki, Finland. He has also worked at the Swedish National Board of Fisheries, in the Institute of Coastal Research. His research concerns management of pikeperch fisheries in the coastal waters of the Baltic Sea. His address: Department of Biological and Environmental Sciences, P.O. Box 65, FIN-00014 University of Helsinki, Finland.
kari.saulamo@helsinki.fi

Gunnar Thoresson (deceased January 2004), was formerly department head at the Swedish National Board of Fisheries, Institute of Coastal Research. His research was focussed on both fishery statistics and coastal zone management in the Baltic Sea. In recent years he worked with local management issues, bridging the gap between commercial and recreational fishery.