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Interdisciplinary modelling though probabilistic networks: impact of fishermen's commitment on the management of wild Baltic salmon stocks

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Abstract

Till now the restoration of potential wild Atlantic salmon populations has known relatively little success. In order to increase the probability of success, it is necessary to examine the possible factors that are currently limiting the rehabilitation of these salmon stocks and which remedial management measures can be taken. Management measures however, do not directly affect the salmon populations. Instead they are targeted at the fishermen. The impact of management measures on the fish stocks is therefore dependent on the reaction or commitment of fishermen to the management measures. The commitment of the fishermen however is quite uncertain. A probabilistic net has been constructed to look at the impact of fishermen's commitment on the fish stocks. This net combines biological information on the wild Baltic salmon stocks with socio-economic information from the fishermen. Low commitment of fishermen will decrease the impact of management actions on the fish stock. In order to select appropriate management measures to increase the probability of successful rehabilitation of potential salmon rivers, information on the fishermen's reaction to different management measures is needed. Larger uncertainty about the fishermen' s commitment to different management actions will result in a lower control over the system.

Keywords: fisheries management, commitment, interdisciplinary, Bayesian network

Introduction

During the 20th century, damming of the rivers and pollution caused a serious decline of the Baltic Salmon stocks (Salmon salar) (Karlsson and Karlström 1994). In order to replace the lost production of wild saolmon, ariticial salmon rearing programs were started. Thanks to the mitigation stocking program in the Baltic Sea, a steady supply of catchable salmon have been provided over the years, allowing a high catch-per-unit-effort in the offshore fisheries (Eriksson and Eriksson 1993). However, this also caused high exploitation rates on the remaining wild salmon stocks. Consequently, several wild salmon populations had declined to a fraction of its original size and were close to extinction in the 1980s (Romakkaniemi 2003). Stocks from three rivers, Kuivajoki, Kiiminkijoki and Pyhäjoki, even disappeared completely (Figure 1).

During the 1970s and 1980s enhancement or augmentation programmes were set up for different wild salmon rivers in the Baltic Sea in order to help these rivers in their recovery. Through stock enhancement, interbreeding of hatchery-reared fish with wild salmon was encouraged in order to increase the stock production (Cowx 1994). In 1976 the International Baltic Sea Fishery Commission (IBSFC) was established with the aim to regulate the exploitation of the salmon stocks. In 1991 the TAC system was introduced, which has been lowered over the years, and in 1997 IBSFC launched the Baltic Salmon Action Plan (SAP). The objective of the SAP is to increase the natural production of wild Baltic salmon stocks to at least 50% of the natural smolt production capacity by 2010 while at the same keeping the cathes as high as possible. The IBSFC Salmon Action Plan also suggested to reintroduce salmon population in potential salmon rivers, i.e. old salmon rivers that have lost their salmon population due to overexploitation, habitat degradation, dam rebuiding or pollution (IBSFC and HELCOM 1999).

Since the Salmon Action plan was adopte, the total wild smolt production has increased from 0.5 million smolts to about 1.7 million smolts in most recent years. This is estimated to be around 48% of the overall potential smolt production (ICES 2005). However, this development is not uniform among rivers; the number of smolts increased in the larger salmon rivers, whereas numbers remained low in many weaker stocks (Figure 2). The number of spawners is particularly low in the potential rivers, e.g. the river Kuivajoki, Kiiminkijoki and Pyhäjoki.

Within this paper we try to look in the first instance at the differences between the river Simojoki, a wild salmon river, and potential salmon rivers in terms of the biological characteristics of the salmon population, the fishing pressure on the population and the river's socio-economic and biological environment, and which of those factors are currently limiting the re-establishment of salmon populations in potential salmon rivers. Thereafter we try to look at which management measures could be taken to increase the probability of successfully establishing salmon population in potential salmon rivers while taking into fishermen's commitment. The current paper only illustrates how the different disciplines can be integrated with one methodology. More work will be needed in order to fully obtain this integration.

Methods

The question about the differences in biological and socio-economical circumstances between rivers can be answered through separate biological, economical and socio-economic studies. The results from the different disciplines can later be linked together within one single probabilistic or Bayesian network model (also caalled Bayes' network or Bayesian belief network) (Jensen 2001). This interdisciplinary model expresses the conditional relationships between model variables in a probabilistic way (Figure 3). For example, the number of adult salmon spawning in the river is conditional on the number of salmon available to the fishery and the behaviour of the fishermen in terms of fishing effort while the fishing effort itself is conditional on the number of available fish, the economic interest of the fishermen, and the commitment of the fishermen to safeguard Baltic salmon stocks.

The probabilistic network has the advantage that the collection of data and their analyses don't have to be conducted in a unified format over the different disciplines. Instead the probabilities for the different conditional relationships can be obtained through different methodologies. In the case of Baltic salmon, the biological estimates within the Bayesian network are obtained through a probabilistic mark-recapture model of tagging data (Michielsens et al. In Press, Michielsens et al. 2005), the economic dependencies are obtained through bio-economic models (Laukkanen 2001, Kulmala et al. 2005) and contingent valuation (Navrud 2001, Parkkila 2005), while the social dependencies come from questionnaires and in-depth interviews with key people (Haapasaari et al. 2005, Reinikainen et al. 2005). Network modelling allows us to examine not only what has happened in the past but through the expression of causal relationships within the model structure, it also allows us to examine what would happen to the salmon populations if certain biological, economical and social conditions in potential salmon rivers would be different (Pearl 2000). It would therefore be possible to examine the effect of different management actions on the fishing behaviour of the fishermen in the different rivers and to examine for each river which combination of management actions has the highest probability of successfully restoring the salmon stocks.

Data

The main source of information for the biological part of the model has been obtained from tagging data of the rivers of interest i.e. Simojoki, Kuivajoki, Kiiminkijoki and Pyhäjoki. Between 1987-2002 a total of 51,000 salmon have been tagged and released within these rivers of which 42% in the potential salmon rivers. In order to improve the estimation process, additional tagging information from 234,000 tagged salmon from the rivers Kemijoki, Iijoki, Oulujoki and Tornionjoki have been used within the same mark-recapture analyses while taking into account any difference in life histories, life history parameters and exploitation rates (Michielsens et al. In Press, Michielsens et al. 2005). The number of hatchery-reared released salmon smolts have been obtained from the ICES report of the Baltic salmon and trout working group (ICES 2005). Probability distributions for the number of wild smolts and released hatchery-reared salmon parr have been obtained by smolt trapping (Simojoki) or by applying a linear regression analysis to convert parr density estimates into smolt abundance estimates (Kuivajoki, Kiiminkijoki and Pyhäjoki) (ICES 2005). The form and parameter values of the stock-recruit relationship for the river Simojoki have been obtained from Michielsens and McAllister (2004) and the ICES report of the Baltic salmon and trout working group (2005). Because in potential salmon rivers, natural reproduction has been very low or non-existent, it has not been possible to estimate stock-recruit relationships for these rivers. In order to reflect any differences in river quality of potential salmon rivers in comparison to the river Simojoki, expert opinion has been used to estimate the stock-recruit parameters (Michielsens et al. 2005). The natural mortality estimates, due to the occurrence of M74 at the alevin stage, which affect the stock-recruit relationship, has been estimated for the Simojoki salmon stock through an hierarchical model of M74 data obtained from the salmon hatcheries (ICES 2005). It is assumed that potential salmon rivers have been affected similarly as Simojoki.

As seen in Figure 3, the belief network also takes into account the commitment of fishermen towards the recovery of potential salmon rivers. The factors that determine fishermen commitment have been explained by Haapasaari et al. (2005) within a socio-economic belief network (Reinikainen et al. 2005). The initial structure of that network has been the outcome of interviews with key-people while the probabilities to express causal dependencies have been obtained through structured questionnaires based on the initial network and send to 1000 fishermen of which about one third returned the questionnaire. In addition expert opinion has been used to predict the outcome of different management, knowledge and commitment actions on model parameters on which they have a direct impact. Through the causal relationships, the model thereafter predicts the impact of the different actions on commitment.

For the economical part of the belief network, information on fishing cost and fish prices have been obtained (Kulmala et al. 2005). The fishing cost data have been obtained though informal interviews of fishermen. The analysis takes into account variable fishing costs: price and fixing costs of a gear, vessel reparation costs, fuel and working costs. Fish prices for the professional fisheries have been obtained from official price statistics (FGFRI 2004). Fish prices for the recreational fishery have been obtained through contingent valuation (Parkkila 2005). These inputs have been used to calculate the net economic benefits for the different groups of fishermen (Kulmala et al. 2005).

Results and discussion

The different salmon stocks have been compared in terms of their ability to reach the SAP management objective i.e. to reach 50% of the smolt production capacity. Figure 4 shows the results for the different rivers for the periods 1999-2002 (derived from hatchery-reared salmon releases before the start of the SAP), 2003-2006 and 2007-2010. For the river Simojoki, the amount of wild salmon smolts has increased significantly compared to the amount of wild salmon estimated before the start of the SAP and there will be almost 80% probability that the wild salmon smolts will reach 50% of the smolt production capacity by 2007-2010. For the potential salmon rivers, the probability to reach 50% of the smolt production capacity by 2007-2010 is lower. The graph clearly illustrates that in case of the river Kuivajoki the probability of successful recovery at the current moment is still very low. Examining the results for the river Pyhäjoki, there should however have been clearer signs of stock recovery in this river. The lack of signs on the recovery of the river Pyhäjoki could be explained by the fact that the river Pyhäjoki has known some very dry years, hampering the salmon's access to the river. In addition it could be that the river quality is even worse than anticipated. By 2007-2010, there should however be a clear increase in the number of wild smolts produced in all potential salmon rivers provided that exploitation rates and M74 mortality rates remain the same.

The stock-rebuilding program in Finland relies heavily on the release of hatchery-reared salmon. Based on the results in Figure 4 for the river Simojoki, it could be argued that the amount of wild salmon smolt in 1993-1996, in combination with the reduced fishing pressure since the start of the SAP program, made it unnecessary to supplement the population with hatchery-reared salmon. Figure 5 demonstrates that if such a strategy would have been followed for the river Simojoki, the probability of reaching 50% of the smolt production capacity by 2010 would be very low. Both the commercial offshore fishery as well as the coastal and river fishery would need to be closed entirely in order to obtain a sufficient increase in the probability to reach 50% of the smolt production capacity by 2010 and even then the probability reaches only about 60%. Based on Figure 5 and the fact that potential salmon river are less productive than the Simojoki river stock, it becomes clear that the stocking of hatchery-reared salmon is an important management tool for the re-establishment of potential salmon rivers.

One of the reasons for the limited amount of wild salmon smolts produced by potential salmon rivers has been believed to be the high efficiency of the fisheries. Based on Figure 4 it can be stated that at the current rate of exploitation, even though the exploitation of the rivermouth fishery in some potential salmon rivers like the river Kiiminkijoki is higher than in the river Simojoki, it should be possible for potential salmon rivers to recover. Figure 6 explores the probability of successful recovery of the river Kiiminkijoki by 2007-2010 under different hypotheses about the exploitation rates. The results indicate that the fishing measures taken since the start of the SAP clearly had a positive impact on the probability of successful recovery of this river and further decreases in the fishing pressures by different fisheries starting in 1997 would have further increased the probability of successful recovery by 2010.

A lot however depend on the reaction of the fishermen on any increase of the salmon population within these rivers. If the fishermen belief that the river quality is unsuitable for reproduction and that the released salmon will not be able to reproduce, fishing is likely to increase as the number of returning spawners increases. Results from the socio-economic network (Haapasaari et al. 2005) indicate that overall commitment of recreational fishermen towards the restoration of potential fishermen is greater than the commitment of professional fishermen who have a lot more vested interests. Nonetheless coastal fishermen have more confidence in the suitability of the river conditions than rivermouth or river fishermen, with the exception for the river Simojoki. The closer towards the river, the greater the amount of wild salmon the fishermen think they catch, even though this is still believed to be less than 80% within the river. In the rivermouth, the fishermen belief they are catching only around 40% of wild salmon. In combination with the belief that river conditions are unsuitable for reproduction, as is believed for potential salmon rivers, this could lead to high exploitation rates as the number of returning spawners increases. This seems to be already the case for the river Kiiminkijoki where the amount of wild salmon within the catches is believed to be very low in the rivermouth and where most fishermen belief that river conditions are unsuitable for reproduction. In contrast to the other potential salmon rivers, in the river Kiiminkijoki there have already been signs of some increase in the amount of spawners returning to the river and subsequent natural production. The beliefs however of the rivermouth fishermen may consequently lead to even higher fishing pressures as the number of returning spawners increases further.

At this stage in the recovery of potential salmon rivers, any increase in the number of returning spawners should be consolidated by not allowing the fishing pressure to rise to a similar extent with rising abundance numbers. In order for any management actions to have a positive effect on the exploitation potential salmon rivers, the management actions need to have the support of fishermen. Professional and semi-professional fishermen prefer management measures which tread every group of fishermen in the same way i.e. that they would be affected to the same extent. Unlike in the Simojoki river fishery, where the majority of fishermen would prefer quotas as the most suitable management action to increase the probability of successful recovery, river fishermen in potential salmon rivers would recommend stocking more fish and while at the same time treating everyone in the same way in case fishery exploitation needs to be reduced.

The current belief network sets the first steps in trying to take account of fishermen's commitment and their reactions towards different management actions when evaluating the impact of different management actions on the stocks of interest. At this stage of the research, a greater understanding of both the biological and socio-economic factors have been gained i.e. which factors are currently limiting stock-recovery in potential salmon rivers and what management actions can be taken to try to increase to increase successful recovery of potential salmon stocks. Further integration of the results in the belief network is needed in order to be able to evaluate which management actions lead to high probabilities of successful recovery of potential salmon stocks. However, as can be seen from the description of the data, information on potential salmon rivers is quite sparse and uncertain. This should be taken into account when evaluating the probability to reach 50% of the smolt production capacity. Because the probabilistic network takes into account all the uncertainty associated with the status of potential salmon rivers it might be impossible to reach a high probability of successful recovery, simply because of the uncertainty in the estimates.

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Table 1: List of symbols used within the model

	Indices
y	Year group in which the salmon have been smolts i.e. 1993-1996, 1997-2000 and 2001-2004
r	Salmon river in which the smolts have been released or reared i.e. Simojoki, Kuivajoki, Kiiminkijoki and Pyhäjoki
t	Type of salmon smolts i.e. wild salmon smolts, reared salmon smolts released as parr and reared salmon smolts released as smolts
s	Stage within the salmon life cycle i.e. smolts (1), feeding salmon within the Main Basin (2), salmon migrating back to river (3), salmon near or in the rivermouth (4), adult salmon with the river (5), spawners (6)
l	Location or area of the salmon stocks i.e. the river (1, 5 and 6), the Baltic Main Basin (2), coastal areas of the Bothnian Sea (3) and coastal areas in the Bothnian Bay near or in the rivermouth (4)
	Model parameters
$M_{1,y,t}$	Average instantaneous natural post-smolt mortality rate for smolts of type t originating from smolt year group y (year^{-1})
$M_{s\neq 1}$	Average instantaneous natural adult mortality rate (year^{-1})
$M_{0,y}$	Average natural mortality due to the occurrence of M74 at the alevin stage on salmon originating from smolt year group y (year^{-1})
C_l	Commitment towards SAP program by fishermen active in area l
E_l	Economic fishing interests by fishermen active in area l
SR_r	Stock-recruit parameters for the salmon stock in the river r
	Model variables
$N_{s,y,r,t}$	Average abundance of salmon at stage s, which had occurred in river r as type t smolts originating from smolt year group y
$F_{l,y,r,t}$	Average instantaneous fishing mortality rate for the fishery in area l, on salmon of type t originating from river r and smolt year group y
	Management actions
$A_{f,l}$	Fisheries management action in fishing area l
$A_{c,l}$	Commitment action targeted towards fishermen fishing in area l
$A_{k,l}$	Knowledge action targeted towards fishermen fishing in area l

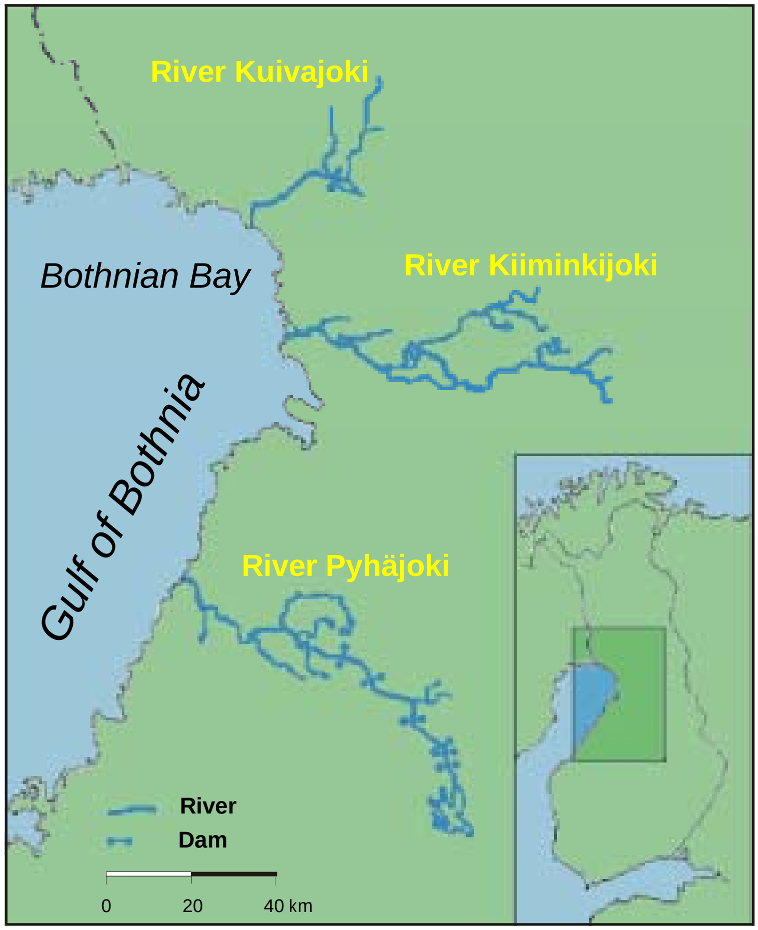
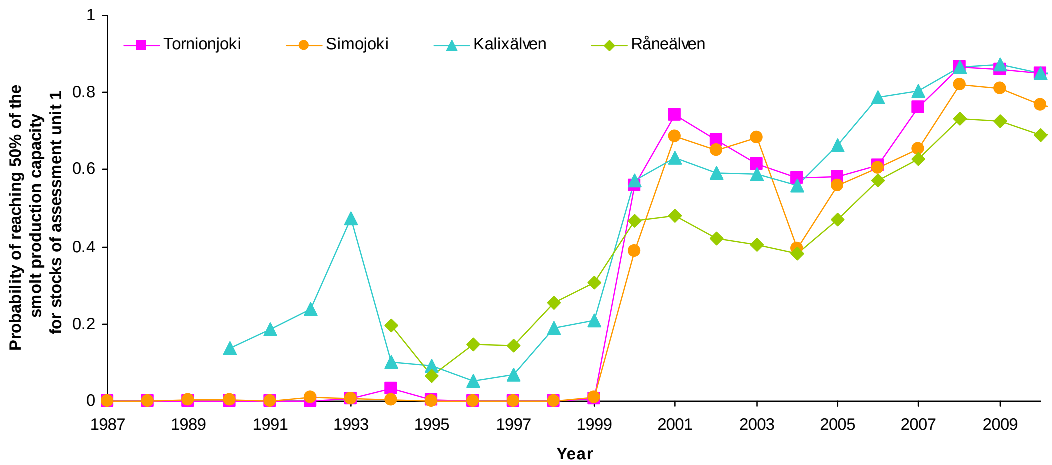


Figure 1: Location of the 3 Finnish potential salmon rivers i.e. the rivers Kuivajoki, Kiiminkijoki and Pyhäjoki, in the north-eastern part of the Baltic Sea. In these rivers the original salmon stocks had disappeared but wild salmon stocks have been re-introduced after improvements to the river habitat.



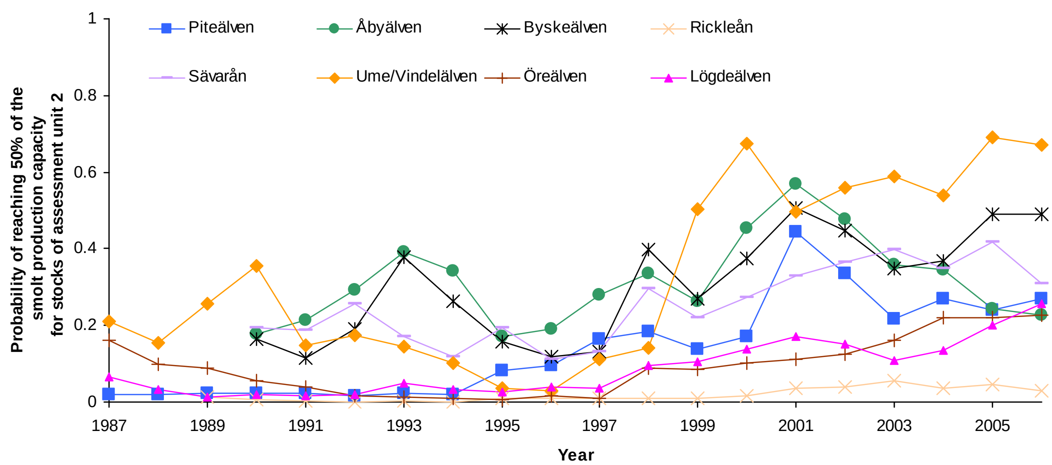


Figure 2: Probability to reach 50% of the smolt production capacity for wild salmon rivers in the north-east and north-west of the Baltic Sea. For the north-eastern stocks (panel 1), smolt abundances are predicted up to the year 2010. For the north-western stocks (panel 2), smolt abundances could only be predicted up 2006 due to the lack of appropriate stock-recruit functions for these rivers. Theoretically, the yearly estimates can exceed 1 because the smolt production capacity is defined as the long-term average.

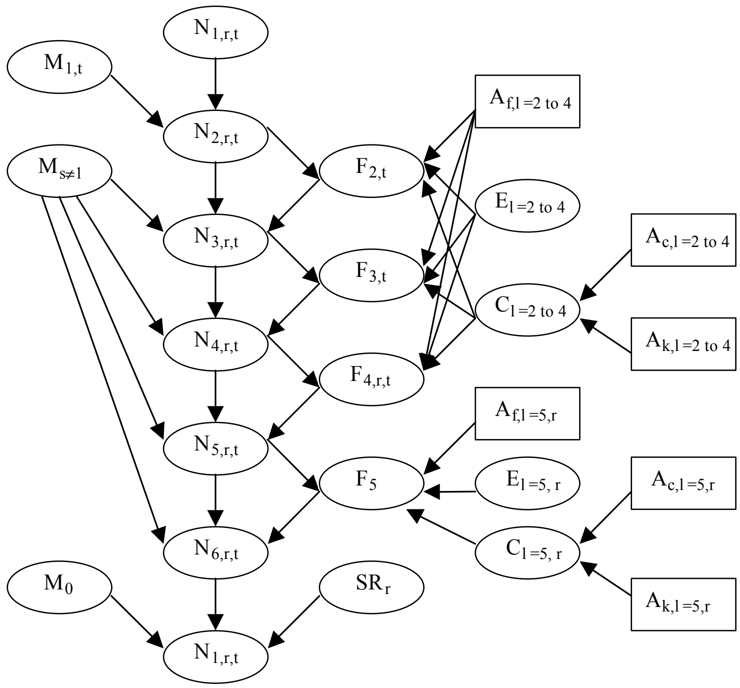


Figure 3: Causal Bayesian network of different factors affecting the survival of salmon smolts and their probability to produce wild salmon offspring, including different management actions which will affect the probability of successful recovery of wild and potential salmon stocks. A description of the symbols used within the model can be found in Table 1.

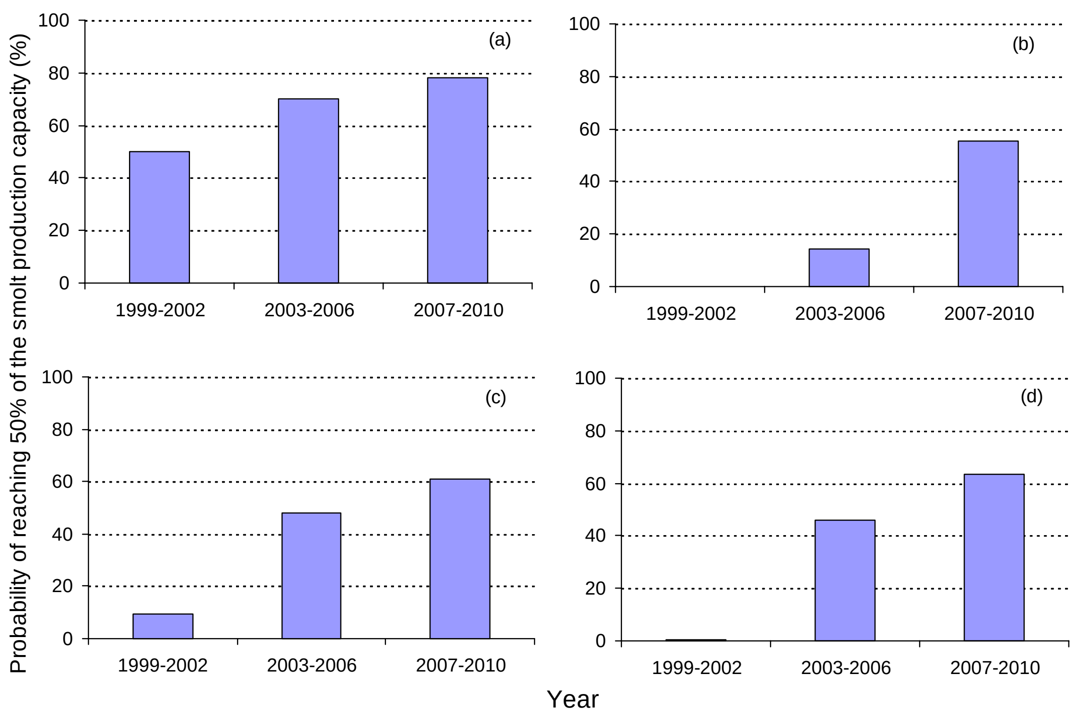


Figure 4: Probability that the amount of wild salmon smolts will reach 50% of the smolt production capacity in the rivers Simojoki (a), Kuivajoki (b), Kiiminkijoki (c) and Pyhäjoki (d).

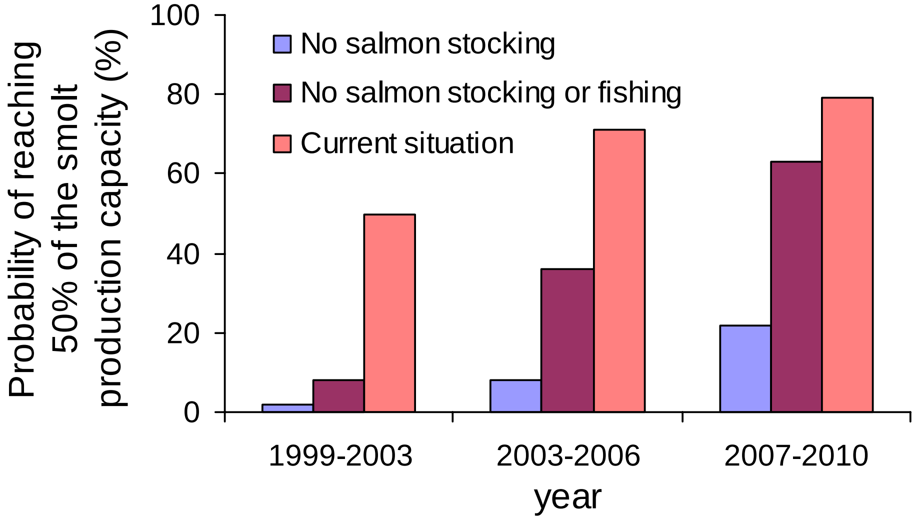


Figure 5: Probability that the amount of wild salmon smolts will reach 50% of the smolt production capacity in the river Simojoki. The first scenario assumes no stocking of hatchery-reared salmon from 1993 onwards, the second scenario assumes no stocking or fishing and the third scenario assumes historic stocking and fishing levels.

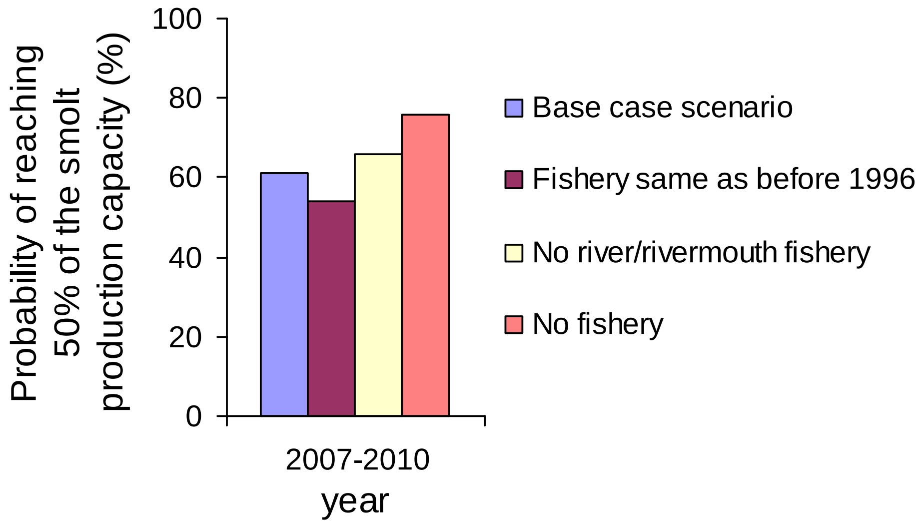


Figure 6: Probability that the amount of wild salmon smolts will reach 50% of the smolt production capacity by 2007-2010 in the river Kiiminkijoki. The first scenario assumes history stocking and fishing levels, the second scenario assumes that the fishing pressure had remained the same as before the start of the SAP, the third scenario assumes the historic offshore and coastal fishing pressure but no river or rivermouth fishing since 1997. The last scenario assumes a complete ban of all fishing activities starting in 1997..

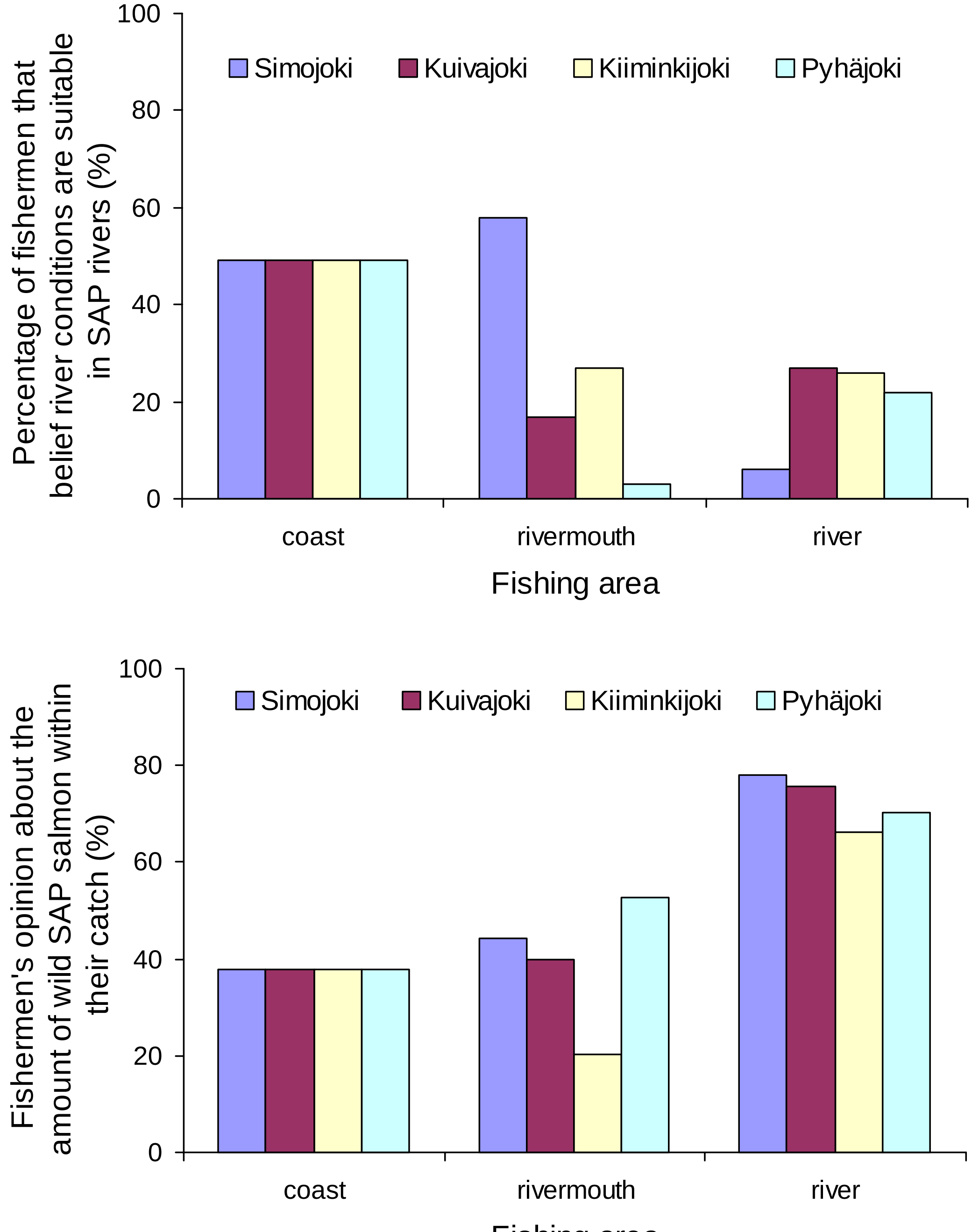


Figure 6: Percentage of fishermen from different areas that belief river conditions are suitable for successful re-establishment of potential salmon rivers (panel 1) and fishermen's opinion about the amount of wild salmon from potential salmon rivers within their catches (panel 2).

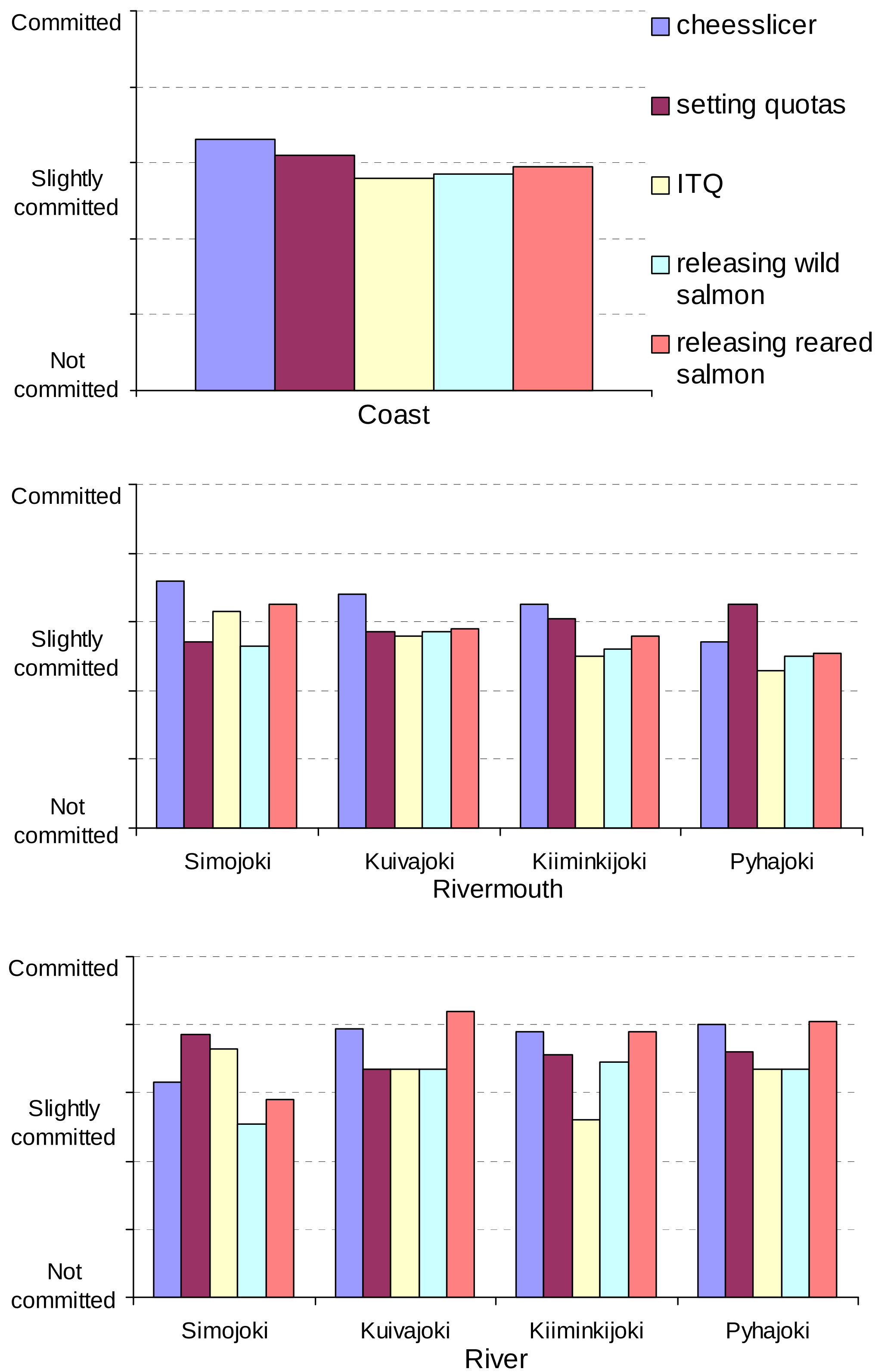


Figure 7: Commitment of fishermen fishing in different areas i.e. coast, rivermouth and river towards different management actions.