Towards Bio-Economic Stock Assessment through Open-Source Framework: A Case-Study of Baltic Salmon

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Abstract

The paper puts forward a simulation model currently used in the Baltic salmon stocks assessment. The model accounts for full life-history of 15 naturally reproducing and 6 hatchery-reared salmon stocks. Designed to help identify economically and biologically sound management recommendations, the model accounts four countries whose fleets target salmon with different types of gear in a different time of year. It is calibrated by using the latest stock assessment results and salmon price and fishing costs data from the four countries. The model is executed in an open-source environment. We carry out a retrospective analysis of the international Baltic salmon fishery in terms of economic performance criteria. We use non-cooperative and cooperative game theory to give insights what would have happened if the salmon fishery would have been managed in an economically sound way. The model is easy to apply for every commercial fishery and therefore provides a general tool for bio-economic stock assessment.

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1. Introduction

In the Baltic Sea region, Atlantic salmon (*Salmo salar*) stocks have been and still are the most controversial resources. The management of the fishery has historically been based on biological objectives, however the stocks have decreased over time and in 1997 the now defunct International Baltic Sea Fishery Commission (IBSFC) launched the Baltic Salmon Action Plan (SAP) that aimed to recover the wild Baltic salmon stocks and reach by 2010 a smolt production level that is 50% from the estimated carrying capacity. Due to the life-cycle of salmon the management measures taken from now on will take effect beyond 2010. Further the political situation in the Baltic Sea riparian countries has changed. After Estonia, Latvia, Lithuania and Poland joined to the EU the Russian Federation became the only non-EU-member coastal state of the Baltic Sea. To this end the European Commission has decided to revise the SAP in 2007 and to develop a new management framework for Baltic salmon (European Commission, 2007).

European Commission calls for the socio-economic impact assessment of the forthcoming management measures. Scientifically sound impact assessment must explicitly account for the fishing fleet of the different countries harvesting the salmon as well as the life-cycle of salmon. The objective of this paper is to describe a bioeconomic model that is a tool for the evaluation of the potential management options from economic and biological point of view. The model takes into account the full life-history of 15 wild and 6 hatchery-reared salmon stocks. The economic part of the model considers four countries targeting the salmon: Finland, Sweden, Denmark and Poland. The fishing fleet of each country consists of two to five different types of commercial fisheries that are modelled sequentially in time and the order of fisheries is determined by the feeding and spawning migrations of salmon. The underlying population dynamic model is used in the International Council for the Exploration of the Sea (ICES) stock assessment Working Group for Baltic Salmon and Trout (WGBAST) to assess the status of the stocks and to provide the scientific advice on the total allowable catch (TAC) (ICES, 2007).

European Union's Common Fisheries Policy (CFP) affects the salmon fishery by setting the upper limit for the salmon catch. Each country's fishing possibilities are defined by the Relative Stability principle according to which the TAC is shared to the EU-countries. Essential for the socio-economic impact assessment is to identify the different user groups of salmon and assess the effects of the different management options on all groups. Despite the country specific TAC, the countries targeting salmon are interdependent since the harvest of each country affects the profits of other countries and reduces the future salmon stocks. In the case of migrating species the same applies to the sequential fisheries. Game theory provides a tool to analyse such connections.

The present study constructs and calibrates the bioeconomic model so that it can be used in the socio-economic impact assessment of the forthcoming international Baltic salmon fisheries management scheme. We carry out a retrospective analysis of the international Baltic salmon fishery. We focus on years 1995-2005 and analyze the past fisheries policy in terms of the objective of SAP and in terms of economic performance of the salmon fishery. We analyze the fishery under four different scenarios and ask what had happened to the salmon stocks and the profitability of the fishing sector under the past fisheries policy and then we use non-cooperative and cooperative game theory to give insights what would have happened if the salmon fishery would have been managed in an economically sound way.

The objective of the present paper is to execute the simulation model in an open-source environment by using Fisheries Library for R (FLR) that is a tool to facilitate a multidisciplinary modelling work and fisheries strategy evaluation. FLR is implemented using object-oriented programming. For instance, you put all the biological data and the population dynamics under a stock object and similarly the data from the fishing fleet you put under a fleet object. The objects consist of several multidimensional arrays that store the data in a particular way. Using a standard way to store the data facilitates the development and the utilization of general methods. Further, the standard class structure makes it easier to follow programs developed by other modellers, since the data should always be stored in a similar manner in all programs. (Kell et al, 2007; http://flr-project.org/doku.php; http://flr-project.org/doku.php?id=appl:salmon)

The study extends the bioeconomic literature on the optimal management of salmon (Charles & Reed, 1985; Laukkanen, 2001; Laukkanen, 2003; Kulmala et. al, 2007a). Laukkanen (2001; 2003) considers the Baltic salmon stocks as total biomass and Kulmala et al, 2007 focuses on the age-structure and harvest on one salmon stock. However, they restrict the number of adult age groups of salmon. Further, the present study extends the literature by considering the Baltic salmon fisheries in the international framework. We provide an optimal open-loop solution for each country, further our results give insights to the optimal fishery configuration of each country.

2. Bioeconomic simulation model for international Baltic salmon fishery

The Baltic salmon fishery is regulated under European Union's Common Fisheries Policy (CFP). In addition to international management measures the states of the Baltic Sea have their own national salmon fishing regulations. At the international level, decision of TAC (total allowable catch) is made annually. The quota is allocated among Baltic Sea riparian countries according to relative stability principle. Nationally, the countries can set for instance fishing time restrictions.

A characteristic for the salmon fishery in the Baltic Sea is that there are several sequential fisheries which differ from each other in terms of fishing time, place and gears harvest salmon sequentially. Offshore driftnet and longline fisheries harvest feeding salmon in winter in the Baltic Main Basin and coastal fisheries operating with trap, drift and gillnets harvest spawning migrating salmon in the Gulf of Bothnia in summer and finally, in autumn, when spawners reach their home rivers they are harvested by anglers. In the Gulf of Bothnia, spawners migrate mostly along the Finnish coast. Offshore and coastal fisheries are mainly commercial while the river fishery is recreational. (see Figure 4 on p.8 and Figure 5 on p.9)

Fisheries economists' models have been accused of simplifying the dynamics of populations and that may be one reason for the ignorance of fisheries economics results among managers (Deacon et al. 1998). In order to response to this criticism and in order to provide economically sound management options for Baltic salmon fisheries we will base our model on the salmon population dynamic model used in the ICES Baltic Salmon and Trout Assesment Working Group (WGBAST) (ICES, 2007).

The population dynamic model of Baltic salmon considers the life-cycle of salmon and the migration pattern that is the model dimensions include time and space. The model observes wild and hatchery reared salmon in the ICES stock assessment units 1-6 (Figure 1). Each assessment unit includes 1-8 wild salmon stocks. The present model differs from the stock assessment model by observing the reared salmon from assessment units 5 and 6 that are excluded from the stock assessment model[†]. By assumption, the salmon from these two assessment units have similar

[†] Reared salmon from the assessment units 5 and 6 contributes to the salmon catches significantly, however the reared salmon do not reproduce and thus far it does not have an effect on the population dynamics of wild salmon, and therefore it is insignificant from the stock assessment point of view.

migration pattern than the salmon at the assessment unit 4 (Personal communication, Atso Romakkaniemi, Finnish Game and Fisheries Research Institute).

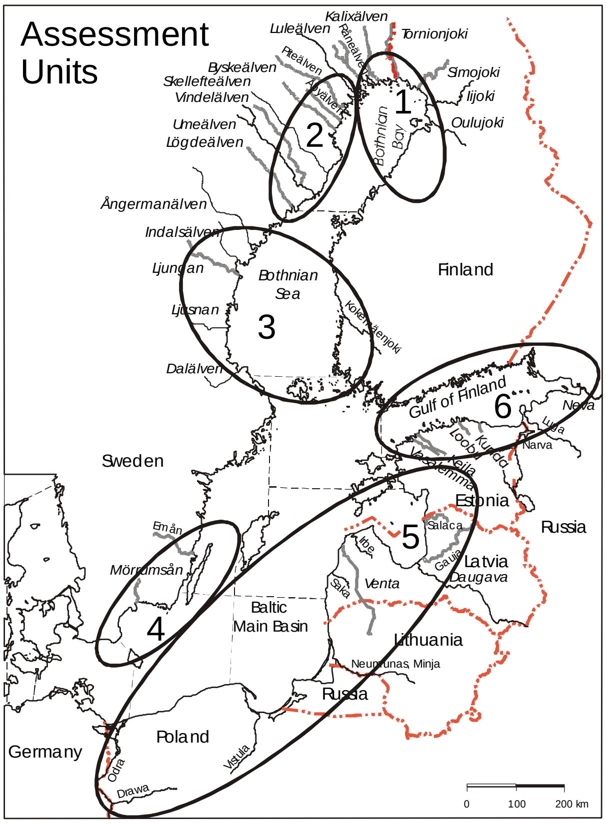

Figure 1. Grouping of salmon stocks in 6 assessment units in the Baltic Sea (ICES, 2007).

2.1 Population dynamics[‡]

The population dynamics equations are of the following general form:

1) $$N_{a,y+1,au,se,st} = N_{a,y,au,se,st} e^{-q_{a,y,f} E_{y,au} m_{a,y}}$$

where $N_{a,y+1,au,se,st}$ is the abundance of salmon by age (*a*), year (*y*), assessment unit (*au*), season (*se*) and stock (*st*), $q_{a,y,f}$ is the catchability coefficient by age, year and fishery (*f*), $E_{y,au,}$ is the fishing effort by year, assessment unit and fishery and $m_{a,y}$ is the instantaneous natural mortality

‡ The population dynamics follows Michielsens et al. 2006

rate by age. In the Bothnian Bay, and additional seal-related mortality factor is used to increase the instantaneous natural mortality rate above the average rate.

Each year, a fraction of the salmon population will mature (L_a) and start spawning migration back to home rivers. Therefore the migrating salmon is given by equation

2) $$N_{a,y,au,se=2,st} = L_a N_{a,y,au,se=1,st} e^{-q_{a,y,f} E_{y,au} m_{a,y}}$$

And the eq. 3 defines the immature salmon stock that stays at the Baltic Main Basin

3) $$N_{a,y,au,se=1,st} = (1 - L_a) N_{a,y,au,se=1,st} e^{-q_{a,y,f} E_{y,au} m_{a,y}} \; .$$

The spawning migrating fraction of the stock is harvested by coastal and river fisheries and the spawners are the salmon escaping from these fisheries. By assumption all salmon die at spawning. The number of eggs produced is given by

4) $$N_{egg,y,au,se=2,st} = SSN_{a,y,au,se=2,st} rs_a \, fe_{y,au,se=2}$$

where SSN is the number of spawners *rs* is the sex ratio and *fe* is the fecundity.

The relationship between the number of eggs and the number of smolts was computed by a Beverton-Holt stock-recruitment function (see, e.g., Michielsens and McAllister, 2004). In the assessment units 1-3 it takes a salmon approximately four years and in the assessment unit 4 three years to develop from eggs to smolts.

The number of smolts in rivers of the assessment unit 1-3 is given by

5) $$N_{smolt,\, y+4,\, au,\, se=2,\, st} = \frac{N_{egg,y,au,se=2,st}}{\alpha + \beta N_{egg,y,au,se=2,st}}$$

and the number of smolts in the rivers of the assessment unit 4 is given by

6) $$N_{smolt,\, y+3,\, au,\, se=2,\, st} = \frac{N_{egg,y,au,se=2,st}}{\alpha + \beta N_{egg,y,au,se=2,st}}$$

where α and β are recruitment parameters.

2.2 Economic Model

The four players are 1) Finland (FI), 2) Sweden (SWE), 3) Denmark (DK) and 4) Poland (POL). Five commercial fisheries from the four countries are considered: offshore driftnet (odn), offshore longline (oll), coastal driftnet (cdn), coastal trapnet (ctn) and coastal gillnet (cgn) fishery. The fisheries are modelled as sequentially in time, so that time and migration status of the fish determine in which fishery it might be harvested. The Finnish salmon fleet consists of all five different fisheries; the Swedish fleet is similar to Finnish fleet except the coastal driftnet fishery. The Danish and Polish fleets include only offshore driftnet and longline fisheries. Further, the same fisheries with different countries are assumed to harvest simultaneously. The economic part of the model does not consider the catches and benefits from recreational river fisheries, but the river catches are taken into account when calculating the number of spawners. A schematic presentation of the bioeconomic model is presented in Figure 2.

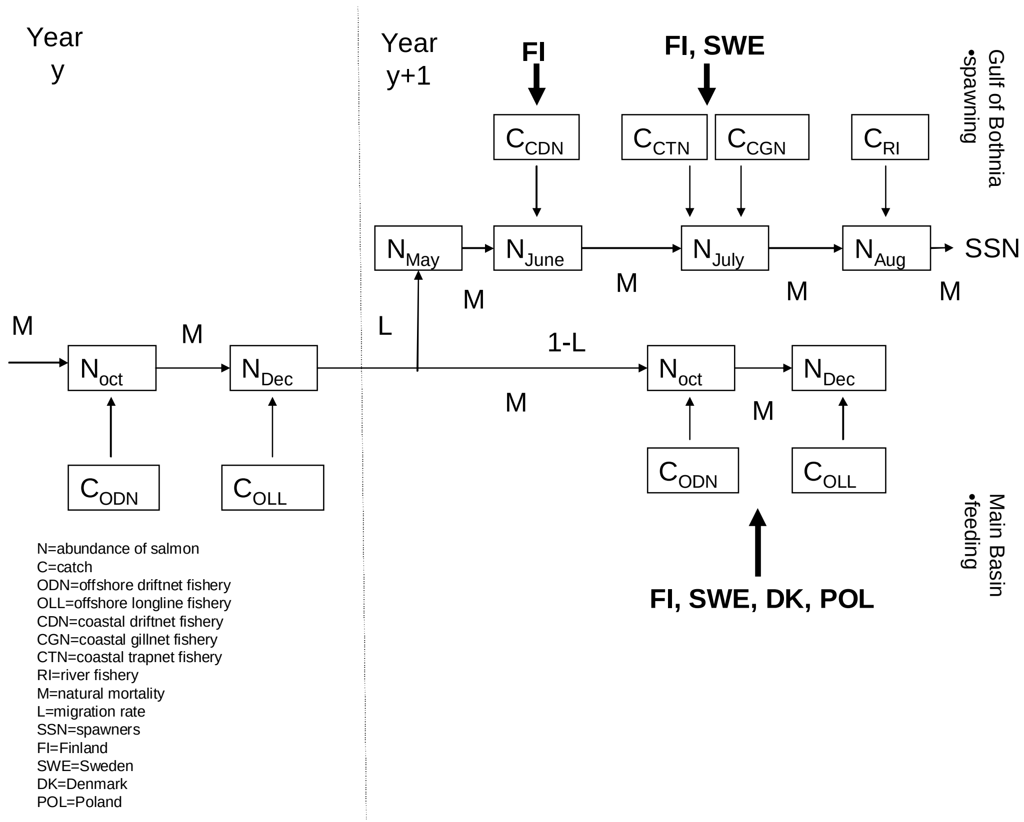

Figure 2. Schematic presentation of the bioeconomic model. All players participate on the offshore driftnet and longline fisheries in October and December. Finland and Sweden targets the spawners in June and July.

The population dynamics model traces the salmon by assessment units. Consequently, the salmon catch is determined by assessment units. In order to trace the salmon catch per country we need to specify each country's proportion from the salmon catch of each assessment units salmon catches. The fishing effort affecting to each assessment unit is a sum of the fishing effort traced by ICES units (iu) (Figure 3.). The ICES units' effort is the sum of the all countries effort in the certain unit. For instance, the effort of the Baltic Main Basin includes effort from the all four countries, but the effort from the Gulf of Bothnia includes only effort from Finland and Sweden. The population dynamic model assumes that due to the migration pattern of salmon the effort from all countries and all ICES units does not have effect on all the assessment units stocks. For instance the salmon from assessment unit 1 (stocks from rivers Tornio and Simo) are not affected by Swedish effort in the Gulf of Bothnia, but during the winter time the adult salmon from the assessment unit 1 is harvested by the all four countries. Further, the population dynamic model assumes same catchability for all countries. Consequently, in order to calculate country specific catches we need to define efficiency parameter to deviate from this assumption.

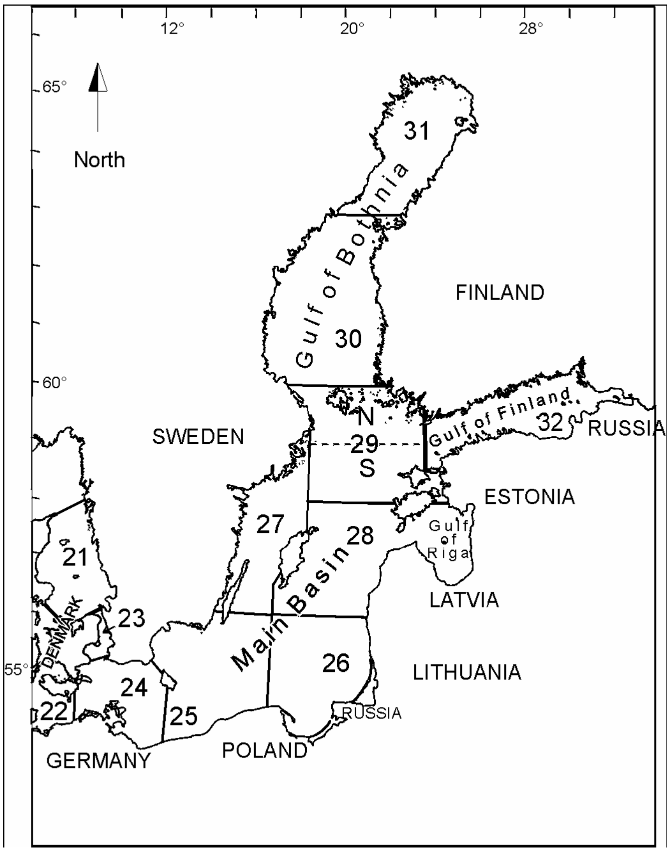

Figure 3. The ICES units according to which the effort is reported. Units 22-29 are consider Main Basin and unit 30-31 refers to Gulf of Bothnia.

The profit function (π) for each country (n) in year y is the following general form:

7)

$$\pi_{y,n} = \sum_{f=1}^{5} \left\{ p_{y,n,f} \left[\sum_{a=1}^{5} \left(\begin{array}{l} \sum_{au=1}^{4} \left(N^{w}_{a,y,au,f} \left(1 - e^{-q^{w}_{a,f} E_{y,au,f} j_{y,au,f,n}} \right) \right) + \\ \sum_{au=1}^{6} \left(N^{r}_{a,y,au,f} \left(1 - e^{-q^{r}_{a,f} E_{y,au,f} j_{y,au,f,n}} \right) \right) \end{array} \right) W_{a,y,f} \right] - c_{y,n,f} E_{y,n,f} \right\}$$

where f refers to a fishery, p is a salmon price a is salmon age, au is assessment unit, w and r refer to wild and reared salmon stocks respectively, N is the number of salmon available to a fishery, W is the catch weight, c is the fishing costs and E is the fishing effort, $j = gPE$, where g is the efficiency parameter and $PE = \frac{E_{y,iu,n,f}}{E_{y,au,f}}$, where $E_{y,au,f} = \sum_{n=1}^{4}\sum_{iu=1}^{3} E_{y,iu,n}$. The sum of net present value of the profits for one country from period 1995-2005 is given by

8) $$\Pi_n = \sum_{y=1995}^{2005} \frac{\pi_{y,n}}{(1+r)^{y-1}}$$

where, r is the discount rate.

3. Model calibration

We calibrate the model by using parameter estimates for the 15 wild and 6 hatchery-reared salmon stocks. The parameter estimates based on the assessments currently used by the corresponding ICES working group (ICES, 2007). The stock assessment uses Bayesian estimations and therefore it provides posterior distribution for almost all population dynamics parameters. The model is calibrated by using the median values of these distributions. Table 1 presents the recruitment parameters alpha and beta for the 15 wild salmon stocks. In keeping with the ICES working group assumptions the reared salmon do not reproduce. The sex ratio for grilse and MSW salmon are 0.2 and 0.5 respectively. Tables 2 and 3 present the fecundity and homing rates by age. The post-smolt and seal-induced mortalities are presented in table 4. The adult natural mortality values for wild and reared salmon are 0.0633. Table 5 presents the number stocked salmon to assessment units five and six and Table 6 presents the catchability coefficients.

Tables 7 and 8 present the fishing effort data for offshore and coastal fisheries (ICES, 2007). The fishing effort of coastal trapnet fisheries is reported by ICES units, where 30 refers to Bothnian Sea and 31 to Bothnian Bay (Figure 3 on p.8). According to WGBAST report (ICES, 2007 p. 7) the Polish effort accounts also fishing effort for sea trout, therefore we use the 2006 values for Polish effort. Kulmala et al 2007 estimated fishing costs for year 2005. Based on these estimations we assume that from 1987 to 2005 the fishing costs have increased by 4% per year. We did not have any cost estimations from Poland, therefore we assume that the fishing costs in Poland had been one third of the costs in Finland. Further, we assumed that the fishing costs of coastal gillnet fishery were 20% less than the costs of coastal trapnet fishery. Tables 9 and 10 present the nominal fishing costs for different fisheries and different countries.

We collected the price data from different sources. The salmon price for coastal driftnet fishery was the Finnish salmon price in Åland in June. (FGFRI). The price for Finnish coastal trapnet fishery was the Finnish salmon price in the Bothnian Sea in July (FGFRI) and the respective value for Swedish trapnet fishery was from Kulmala et al 2007b. By assumption the same prices applied also to the coastal gillnet fisheries. The salmon prices for offshore fisheries in Finland, Sweden and Denmark are from Kulmala et al 2007. However, we had price data from Poland for years 2003-2006. These numbers were wholesale prices and therefore we assumed that the prices paid to fishermen were 30% less than the wholesale prices. Further, we need to made assumptions on Polish prices for 1995-2002 that is we assume that the respective prices were 30% of the average of the prices of the other three countries. (Table 14)

In order to calculate the country specific catches we need to estimate so called efficiency coefficients that determine each country's catch proportion form the total catch of each assessment units. Table 12 presents the coefficients. Tables 13, 14 and 15 present the catch weight data. The age-structured time series data from salmon catch weights is from FGFRI. We assumed that the catch weight for the first sea-age was 0, since the average length of at this age was less than 60 cm that is the legal minimum landing size.

Table 1. Recruitment parameters for wild salmon.

Salmon stock	alpha	beta
Tornionojoki	12,505	0,001084
Simojoki	62,995	0,009611
Kalixälven	12,76	0,001313
Råneälven	21,73	0,015945
Piteälven	18,675	0,02352
Åbyälven	29,445	0,05327
Byskeälven	22,125	0,005599
Rickleån	34,495	0,095725
Sävarån	30,6	0,14705
Ume/Vindelälven	24,825	0,004774
Öreälven	35,06	0,04508
Lögdeälven	30,49	0,03614
Ljungan	37,6	0,3957
Mörrumsån	59,57	0,01041
Emån	346,35	0,030605

Table 2. Fecundity of wild salmon.

age	fecundity
1	6999
2	10070
3	14365
4	20170
5	26810

Table 3. Homing rate for wild and reared salmon.

	Homing rate	
	wild	reared
1	0.136	0.244
2	0.364	0.475
3	0.642	0.646
4<	1	1

Table 4. Seal induced mortality (F_seal) and M74-mortality (M-74).

	F_seal	M_74
1995	1	0,60625
1996	1,0565	0,4479
1997	1,116	0,3471
1998	1,179	0,39
1999	1,246	0,096135
2000	1,317	0,070395
2001	1,391	0,18555
2002	1,391	0,16155
2003	1,317	0,13395
2004	1,317	0,072575
2005	1,317	0,049255

Table 5. The number of stocked salmon in the assessment units 5 and 6 in 1000's of salmon.

Year	AU 5	AU 6
1995	1062	280,5
1996	876	332,5
1997	1250	263
1998	1489	276
1999	1521	352,5
2000	1475	334
2001	1324	443
2002	1203	352,5
2003	1317	325
2004	1084	410
2005	983	428

Table 6. Catchability coefficients for different fisheries. Catchability of coastal trapnet (CTN) and gillnet fisheries varies according to assessment unit (AU).

	Catchability			
	grilse		MSW	
fishery	wild	reared	wild	reared
OLL	0,00869	0,00702	0,00869	0,00702
ODN	0,016	0,0194	0,0138	0,0188
CDN	0,016	0,0194	0,0138	0,0188
CTN (AU 1)	0,0271	0,0181	0,025635	0,02553
CTN (AU2)	0,00792	0,00536	0,011555	0,01155
CTN (AU 3)	0,0252	0,0167	0,0209	0,021005
CGN (AU 1)	0,182	0,687	0,19235	0,21835
CGN (AU2)	0,0362	0,123	0,07274	0,083445
CGN (AU3)	0,0121	0,043	0,069745	0,082215

Table 7. Fishing effort of offshore driftnet (ODN) and offshore longline fisheries (OLL) by country and by year.

	ODN effort (100 000 geardays)					OLL (100 000 geardays)				
	Finland	**Sweden**	**Denmark**	**Poland**	**Total**	**Finland**	**Sweden**	**Denmark**	**Poland**	**Total**
1995	5,88589	4,45105	2,238293	0,923258566	13,49849157	0,4019995	3,30463764	3,617733	0,650277679	7,974647819
1996	3,47977	3,176422	1,192935	0,842792038	8,691919038	1,5468101	1,80896568	5,296208	0,727454834	9,379438614
1997	4,069594	2,74037	4,030783	2,783727394	13,62447439	0,7824856	2,42445731	8,117938	3,128202815	14,45308373
1998	4,102574	4,277893	1,437754	3,512560091	13,33078109	1,4053262	1,99887357	3,616754	2,531585136	9,552538906
1999	3,646608	3,038053	1,384443	2,808957044	10,87806104	2,0506718	3,21182977	7,83079	4,387696472	17,48098804
2000	3,39017	3,431313	2,231072	3,510033605	12,56258861	0,3648103	4,69085335	9,183731	5,345847143	19,58524179
2001	2,820179	3,52466	1,427214	4,555955893	12,32800889	1,3132606	2,55587838	7,915327	5,138383392	16,92284937
2002	1,904052	2,624087	0,7265	3,400018205	8,654657205	0,9494176	4,52696	8,53201	5,791468297	19,7998559
2003	1,69224	3,61401	0,75651	3,203179043	9,265939043	0,82063	4,4684	4,17196	3,412142037	12,87313204
2004	2,01487	2,17835	1,10697	2,778588261	8,078778261	1,211	1,8176	1,88374	2,22159919	7,13393919
2005	2,05779	3,134983	0,65999	2,778588261	8,631351261	1,621	3,1222	4,30406	2,22159919	11,26885919

Table 8. Fishing effort of coastal trapnet (CTN), gillnet (CGN) and driftnet (CDN) fisheries by ICES units and by country.

	CTN effort according to ICES units (1000 geardays)				CGN effort according to ICES units (100 000 geardays)				Coastal driftnet fishery's effort
	Finland (30)	**Finland (31)**	**Sweden (30)**	**Sweden (31)**	**Finland (30)**	**Finland (31)**	**Sweden (30)**	**Sweden (31)**	**(100 000 geardays)**
1995	26,1360	29,4220	12,8232	26,8663	1,3059	0,2194	0,1131	0,1667	4,5286
1996	23,0920	19,6590	4,7497	27,5823	0,8669	0,1372	0,0355	0,0591	0,7869
1997	24,4390	22,1640	7,7249	29,3317	0,8003	0,2741	0,0461	0,0190	1,1821
1998	8,0890	10,6430	6,1459	17,6213	0,0509	0,0330	0,0013	0,0036	1,1239
1999	9,9430	15,4760	8,7569	31,8578	0,0453	0,0480	0,0054	0,0119	1,2658
2000	9,2390	14,1220	8,9265	20,5740	0,0485	0,0347	0,0052	0,0074	1,0701
2001	12,4920	15,4020	9,6230	22,2169	0,0237	0,0150	0,0014	0,0029	1,0266
2002	11,8090	16,2180	12,0346	28,4032	0,0211	0,0167	0,0105	0,0114	0,8636
2003	9,0380	23,5360	5,1290	16,1054	0,0699	0,0179	0,0064	0,0346	0,9502
2004	6,2260	17,3500	6,5489	30,0747	0,0145	0,0273	0,0080	0,0026	1,0365
2005	7,1970	16,1340	5,4532	24,8628	0,0317	0,0129	0,0009	0,0363	0,8422

Table 9. Fishing costs of offshore fisheries

	Offshore longline fishery				Offshore driftnet fishery			
	Finland	Sweden	Denmark	Poland	Finland	Sweden	Denmark	Poland
	€/100 000 gearday				€/100 000 gearday			
1995	83769	44544	81110	27923	117675	122994	257290	39225
1996	87259	46400	84489	29086	122579	128119	268011	40860
1997	90895	48333	88010	30298	127686	133457	279178	42562
1998	94682	50347	91677	31561	133006	139018	290810	44335
1999	98627	52445	95496	32876	138548	144810	302927	46183
2000	102737	54630	99475	34246	144321	150844	315549	48107
2001	107018	56906	103620	35673	150334	157129	328697	50111
2002	111477	59277	107938	37159	156598	163676	342393	52199
2003	116122	61747	112435	38707	163123	170496	356659	54374
2004	120960	64320	117120	40320	169920	177600	371520	56640
2005	126000	67000	122000	42000	177000	185000	387000	59000

Table 10. Fishing costs for coastal fisheries

	Coastal trapnet fishery		Coastal driftnet fishery
	Finland	Sweden	Finland
	€/1000 geardays		€/100 000 geardays
1995	16022	19613	432141
1996	16690	20430	450147
1997	17385	21281	468903
1998	18110	22168	488441
1999	18864	23091	508793
2000	19650	24053	529992
2001	20469	25056	552075
2002	21322	26100	575078
2003	22211	27187	599040
2004	23136	28320	624000
2005	24100	29500	650000

Table 11. Salmon price for different fisheries

	Offshore longline and driftnet fisheries				Coastal trapnet and gilnet fisheries		Coastal driftnet fishery
	Finland	Sweden	Denmark	Poland	Finland	Sweden	Finland
	€/kg						
1995	2,7	2,8	3,0	2,0	2,7	2,8	2,5
1996	2,4	2,0	2,3	1,6	2,2	2,0	2,3
1997	2,4	1,8	2,4	1,5	2,3	1,8	1,9
1998	2,7	2,3	2,7	1,8	2,5	2,3	2,6
1999	2,9	2,5	2,6	1,9	2,5	2,5	2,7
2000	3,5	2,8	3,1	2,2	3,3	2,8	3,6
2001	3,3	3,0	3,0	2,2	3,0	3,0	3,4
2002	2,8	3,2	3,1	2,1	2,8	3,2	3,4
2003	2,9	3,2	3,1	2,2	2,8	3,2	3,4
2004	2,3	2,5	3,6	2,4	2,0	2,5	2,7
2005	3,1	2,7	2,8	2,5	2,7	2,7	3,2

Table 12. Efficiency coefficients by assessment unit and by fishery.

	Coastal trapnet fishery				Coastal gillnet fishery			
	Finland		Sweden		Finland		Sweden	
	AU 2	AU 3	AU 2	AU 3	AU 2	AU 3	AU 2	AU 3
1992	0,80	0,86	1,19	1,29	0,59	0,69	4,19	4,57
1993	0,80	0,86	1,19	1,29	0,59	0,69	4,19	4,57
1994	0,80	0,86	1,19	1,29	0,59	0,69	4,19	4,57
1995	0,80	0,86	1,19	1,29	0,59	0,69	4,19	4,57
1996	0,69	0,86	1,26	1,69	0,86	0,88	3,09	4,01
1997	0,73	0,85	1,22	1,48	0,97	0,93	2,35	2,25
1998	0,56	0,64	1,20	1,47	0,96	0,99	1,56	1,47
1999	0,52	0,63	1,15	1,41	0,62	0,75	2,44	3,05
2000	0,58	0,66	1,19	1,35	0,82	0,88	2,18	2,17
2001	0,43	0,54	1,32	1,60	0,90	0,93	1,86	2,26
2002	0,61	0,66	1,16	1,34	0,97	1,01	1,05	0,99
2003	0,42	0,58	1,32	1,74	0,77	0,93	1,46	1,75
2004	0,60	0,69	1,08	1,29	0,91	0,76	1,49	1,43
2005	0,49	0,62	1,15	1,51	0,74	0,98	1,23	1,84
2006	0,49	0,62	1,15	1,51	0,74	0,98	1,23	1,84
2007	0,49	0,62	1,15	1,51	0,74	0,98	1,23	1,84

	Coastal trapnet fishery				Coastal gillnet fishery			
	Finland		Sweden		Finland		Sweden	
	AU 2	AU 3	AU 2	AU 3	AU 2	AU 3	AU 2	AU 3
1995	0,80	0,86	1,19	1,29	0,59	0,69	4,19	4,57
1996	0,69	0,86	1,26	1,69	0,86	0,88	3,09	4,01
1997	0,73	0,85	1,22	1,48	0,97	0,93	2,35	2,25
1998	0,56	0,64	1,20	1,47	0,96	0,99	1,56	1,47
1999	0,52	0,63	1,15	1,41	0,62	0,75	2,44	3,05
2000	0,58	0,66	1,19	1,35	0,82	0,88	2,18	2,17
2001	0,43	0,54	1,32	1,60	0,90	0,93	1,86	2,26
2002	0,61	0,66	1,16	1,34	0,97	1,01	1,05	0,99
2003	0,42	0,58	1,32	1,74	0,77	0,93	1,46	1,75
2004	0,60	0,69	1,08	1,29	0,91	0,76	1,49	1,43
2005	0,49	0,62	1,15	1,51	0,74	0,98	1,23	1,84

Table 13. Salmon catch weight for offshore fisheries

Year / Age	Catch weight for offshore fisheries kg/pcs					
	0	**1**	**2**	**3**	**4**	**5**
1995	0	3,3	6,886957	15,3	10,16	13,5
1996	0	4,854762	7,81875	11,16486	12	13,5
1997	0	4,831068	5,932911	11,70588	9	13,5
1998	0	4,613265	6,7	10,91055	10,16	13,5
1999	0	3,457692	3,7	10,91055	10,16	13,5
2000	0	4,035479	5,2	10,91055	10,16	13,5
2001	0	3,746586	4,45	10,91055	10,16	13,5
2002	0	3,27027	7,709677	10,91055	10,16	13,5
2003	0	3,645588	8,783333	9,608333	12,3	13,5
2004	0	3,457929	3,708333	9,042857	8,6	13,5
2005	0	1,8	3,556098	8,641379	8,9	13,5

Table 14. Catch weight for coastal trapnet and gillnet fisheries

Year / Age	Catch weight for coastal trapnet and gillnet fisheries kg/pcs					
	0	**1**	**2**	**3**	**4**	**5**
1995	0,0	2,0	5,2	10,9	12,1	12,9
1996	0,0	2,4	6,1	8,9	11,0	12,4
1997	0,0	1,9	6,0	9,9	7,8	12,7
1998	0,0	2,1	6,1	9,4	11,4	13,0
1999	0,0	2,0	6,2	9,6	8,3	13,2
2000	0,0	2,5	5,8	8,7	10,4	13,4
2001	0,0	2,4	5,9	9,3	11,4	12,7
2002	0,0	2,4	5,9	9,9	12,4	12,7
2003	0,0	1,9	5,1	9,4	11,6	11,2
2004	0,0	2,3	5,7	10,1	10,4	12,7
2005	0,0	2,4	5,7	9,6	12,4	12,7

Table 15. Catch weight for coastal driftnet fishery.

Catch weight for coastal driftnet fishery kg/pcs						
Year / Age	0	1	2	3	4	5
1995	0,0	4,9	6,4	11,8	11,6	14,3
1996	0,0	2,4	6,1	7,3	11,6	14,3
1997	0,0	3,6	5,9	10,0	11,6	14,3
1998	0,0	5,1	7,1	9,6	11,6	14,3
1999	0,0	4,3	6,5	9,8	11,6	14,3
2000	0,0	3,0	6,1	10,9	11,2	14,3
2001	0,0	3,2	6,8	10,2	11,9	16,6
2002	0,0	2,9	5,7	10,4	11,6	13,6
2003	0,0	3,1	5,5	8,4	11,8	14,3
2004	0,0	3,6	5,9	9,3	7,3	12,6
2005	0,0	3,3	6,1	9,8	10,2	14,3

4. Results and Discussion

Table 16 presents the results of the game theoretical analysis. We calculate the outcome of the four scenarios: 1) Non-Cooperative scenario where we assume that each country takes the fishing strategy of the three other countries as given and chooses its strategy without taking into account that its choice may affect the fishing strategy choice of the three other countries (see e.g. Arnason et al. 2001). 2) Historical scenario that calculates the net present value of the salmon fishery for each country under the reported effort levels. 3) Cooperative (A) scenario assumes that the four countries have agreed to cooperate and find a constant fishing strategy that maximise the sum of the net present value of the four countries given that all four countries participate on fishing. 4) Cooperative (B) scenario finds the constant fishing strategy that maximise the net present value from the salmon fishery by allowing the exclusion of some countries if optimal.

The non-cooperative outcome is the Nash equilibrium where Finland and Sweden decrease their fishing effort by 70% from the reported values, Denmark does not harvest and Poland increase its fishing effort 4.2-fold. Compared to the total net benefits under the reported effort levels the rational behaviour yields substantial benefits. The cooperative (A) strategy is to decrease the fishing effort of the all players by 70%. The cooperative benefits exceed the sum of the non-cooperative benefits. However, the total benefits from the salmon fishery can be increased by Finland being the only harvesting country (Cooperation B).

The lower part of the Table 16 presents the net present value per fishery. The Finnish coastal trapnet fishery is making substantial profits under all scenarios. The higher fishing costs and lower salmon price compared to the Finnish offshore fisheries is compensated by the higher catchability. Further the migration pattern of salmon benefits the Finnish coastal fisheries since the salmon from the assessment units 1-3 are available to the Finnish fishery. The Swedish coastal fleet can harvest salmon only from the stocks belonging to the assessment units 1-2. The fishery specific results give insights also to the optimal fishery configuration.

Figure 4 presents the total salmon catch under the different scenarios. TAC has restricted the fishery only during 1995 and 1996. Despite the modifications made to the model used in the respective ICES working group (efficiency coefficients and higher number of reared salmon) the present model fits moderately to the historical catches. The Non-cooperative scenario yields lower catches compared to the historical and reported catches, which in terms of the long term objective of the Salmon Action Plan (SAP) to achieve 50% of the smolt production capacity by 2010 is more biologically sound than the historical scenario (Figure 5) . This is not surprising, since the non-cooperative scenario assumes the rational behaviour of the countries.

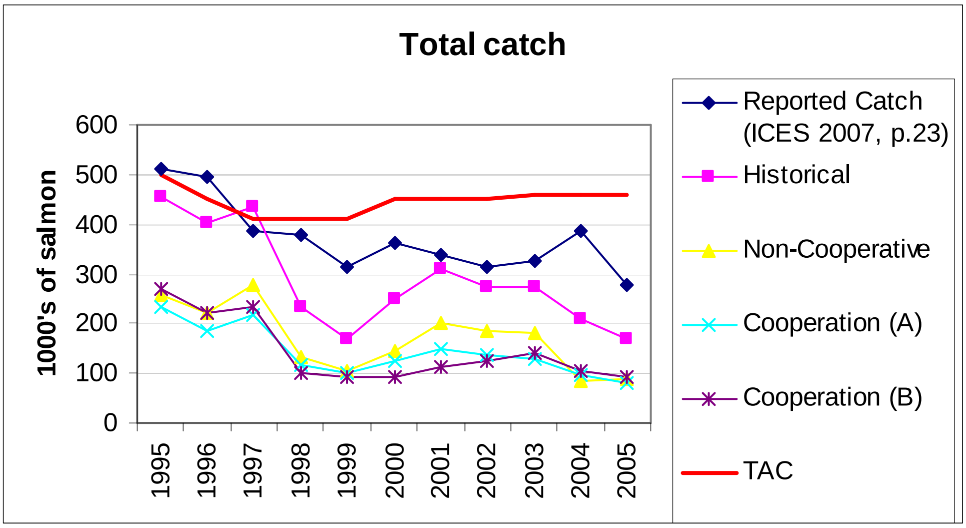

Figure 4. Total salmon catch under different scenarios. Reported catches and TAC are also showed.

Table 16. The net present value of the salmon fishery under the different scenarios by country and by fishery

		FI	SWE	DK	POL	total
Non-Cooperative	Strategy	0,3	0,3	0	4,2	
	NPV(t€)	1044	121	0	568	1733
Historical	Strategy	1	1	1	1	
	NPV(t€)	-2458	-860	-476	52	-3741
Cooperation (A)	Strategy	0,3	0,3	0,3	0,3	
	NPV(t€)	2047	483	219	78	2826
Cooperation (B)	Strategy	0,6	0	0	0	
	NPV(t€)	3332	0	0	0	3332

	OLL					**ODN**					**CDN**	**CTN**			**CGN**		
	FI	SWE	DK	POL	Total	FI	SWE	DK	POL	Total	FI	FI	SWE	Total	FI	SWE	Total
Non-Cooperative	-54	0	0	-116	-170	157	273	0	685	1115	-642	2151	19	2171	-569	-171	-740
Historical	-193	-56	-250	-57	-556	203	570	-226	109	657	-2325	2877	-780	2097	-3021	-594	-3614
Cooperation (A)	-43	39	125	6	127	260	392	94	72	818	-584	2881	219	3101	-468	-168	-636
Cooperation (B)	-85	0	0	0	-85	551	0	0	0	551	-1134	5206	0	5206	-1206	0	-1206

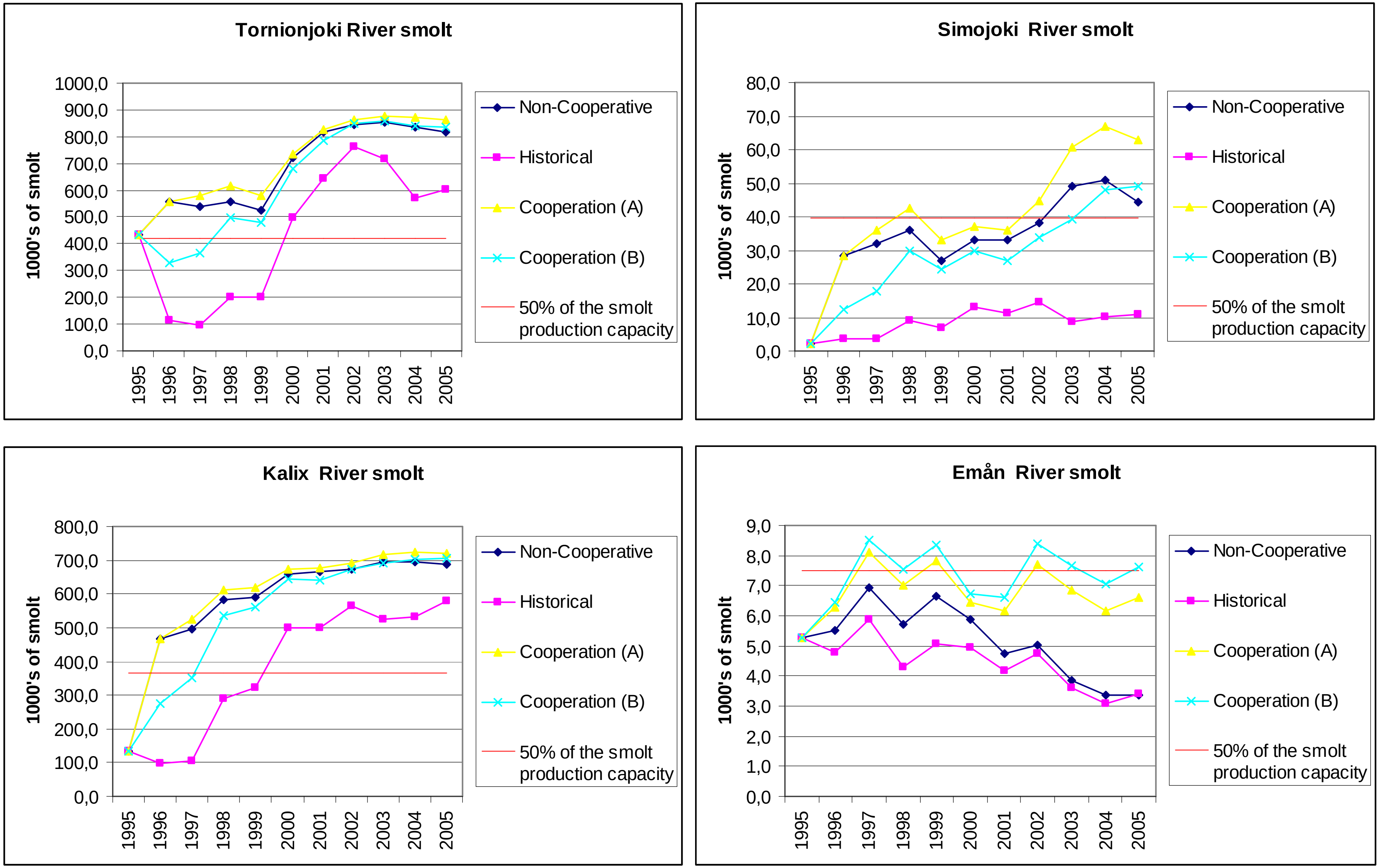

Figure 5. The number of smolt in the four rivers under the different scenarios.

Figure 6 presents the salmon catch per country under the different scenarios, TAC and the reported catch. The reported catch of Sweden and Poland coincides with the TAC. Finland exceeds the TAC in years 1995-1997 and the TAC seems to have restricted fishing mostly in Denmark. Under the Cooperative (B) scenario where Finland is the only harvester it may reduce the effort by 40% from the reported levels and get near the same catch as under the historical scenario. This is due to the fact that under the Cooperative (B) scenario there are more fish available to the Finnish fleet. The assumption of rational behaviour yields zero catches for Denmark and a substantial increase in the Polish catch. This is in line with the result that under the historical scenario Poland is the only country having positive net present value, consequently it is reasonable for Poland to increase its effort while the opposite is optimal for the rest of the countries. However, since the model underestimates the Danish catch this result most likely overdo the inefficiency of the Danish fleet. Further, the non-cooperative catch for Poland violates the relative stability principle according to which Poland's TAC is near 6 % from the TAC allocated to the EU countries.

The results are in line with the ICES Baltic salmon and trout assessment working group recommendation which has raised a need to re-estimate the Polish fishing effort (ICES, 2006, p.206). Consequently, the reported effort used in the historical scenario might underestimate the true effort. Further, the fishery specific results were in line with the results of Kulmala et al. 2006 that showed the profitability of the Finnish coastal trapnet fishery and that the offshore driftnet fishery was economically more effective than the offshore longline fishery. As of 2008, EU fishery regulations will ban the use of driftnets, which in the light of the present analysis may imply that all offshore fisheries may disappear.

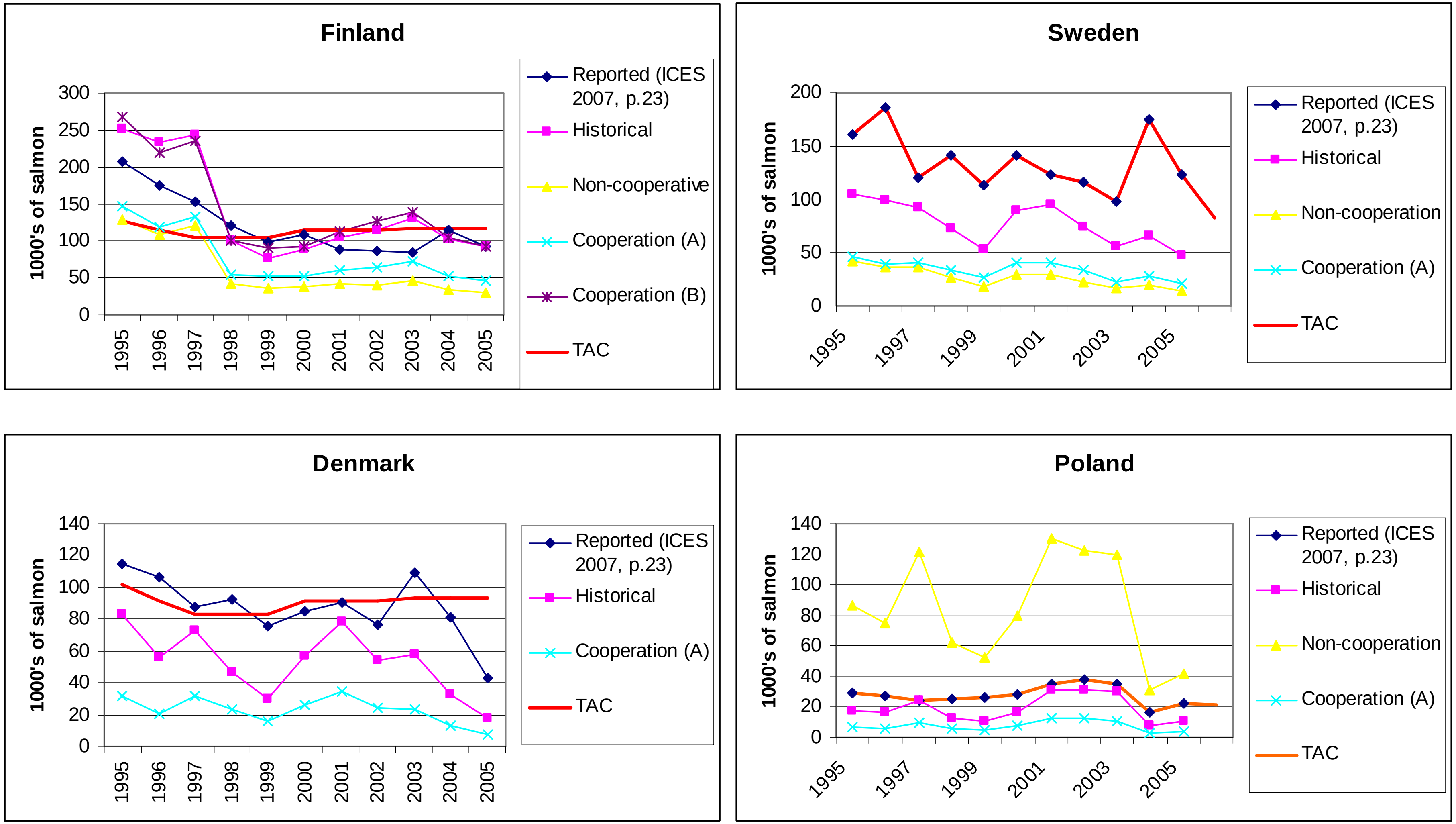

Figure 6. Salmon catch per country under different scenarios

5.Conclusion

The present paper provides a bioeconomic model for the Baltic salmon fishery in the international framework. The model is compatible with the stock assessment models currently used to produce management recommendations of the Baltic salmon fisheries. The model extends the bioeconomic literature of the economically sound management of the salmon by considering the full life-history of 15 wild and 6 hatchery-reared salmon stocks and sequential harvest by multiple fisheries in Finland, Sweden, Denmark and Poland. The model provides a framework towards bioeconomic stock assessment, where the co-operation of fisheries biologists and economists enables to produce management recommendations that consider biological and socio-economic impacts of different management options.

We carry out a retrospective analysis of the Baltic salmon fishery. We focus on years 1995-2005. Firstly, we study the economic performance of the fishery according to the reported effort. We found that the fishery is making substantial losses as a whole, but the Polish fleet is making profits. Secondly, we assumed that the four countries behave rationally and found that the non-cooperative behaviour is Nash equilibrium, where Poland increases its effort substantially, Denmark does not harvest and Finland and Sweden decrease their fishing effort by 70%. Change from the reported effort levels to the non-cooperative behaviour would make every country better of and the total net benefit from the fishery would change from the losses of 3741 t€ to the profits of 1733 t€. Further, our results indicate that the benefits from the cooperation of the four countries would exceed the benefits of non-cooperation.

We conducted the study by using R that is a free language and environment for statistical computing and graphics (http://www.r-project.org/). However, we started the modelling work by applying a specific library for R (FLR, fisheries library for R) designed to facilitate the construction of bioeconomic simulation models of fisheries (Kell et al, 2007; http://flr-project.org/doku.php; http://flr-project.org/doku.php?id=appl:salmon), but it turned out that especially the economic tools under the FLR-framework were on the development stage and not applicable to such complicate problems as the present study is. Further, FLR revealed to be extremely slow in optimization compared to R arrays.

The underlying biological model is complex and the present study reveals that in order to provide economically sound management recommendations the population dynamic model needs further development and the data to calibrate the model should be gathered carefully.

Future research includes a study to determine the conditions under which the cooperative solution is possible to achieve.

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