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Assessment of the eel stock in Sweden, spring 2012

First post-evaluation of the Swedish Eel Management Plan

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This report has been reviewed by:
Jan Andersson, Håkan Wickström

Front and back cover: Jacob van Maerlant (ca. 1235-1300), Der Naturen Bloeme, p. 111. The two drawings (front/back) come from two different editions. The front-piece reads: “Anguilla es die paeldinc bekent; Een visch ghemaekt als 1 serpent”
[Anguilla is as ‘paeldinc’ known; A fish made as 1 serpent].
In Dutch, paeldinc, modern paling, is a (regional) synonym for aal, eel.

Summary

The population of the European eel *Anguilla anguilla* (L.) is in severe decline. In 2007, the European Union decided on a Regulation establishing measures for the recovery of the stock of European eel, obliging its Member States to implement a national Eel Management Plan by 2009. According to this Regulation, Member States will report to the Commission by July 2012, on the implementation of their Eel Management Plans and the progress achieved in protection and restoration. The current report provides an assessment of the eel stock in Sweden as of spring 2012, intending to feed into the coming Swedish post-evaluation reporting.

In this report, the impacts on the stock are assessed - of fishing, restocking and of the mortality related to hydropower generation. Other anthropogenic actions, (climate change, pollution, spread of parasites, disruption of migration by transport, etc) probably have an impact on the stock too, but these factors are hardly quantified and no management targets have been set. For that reason, and because these factors were not included in the EU Eel Regulation, these other factors were excluded from this technical evaluation.

In this report, focus is on the quantification of the biomass of silver eel escaping (actual, potential and pristine) and the mortality endured by those eels during their lifetime. The assessment is broken down on a regional basis, with different impacts dominating in different areas. For the yellow eel fishery on the West Coast, the assessment presented in the Eel Management Plan is extrapolated to most recent years. Since 2009, the fishery has been restricted severely, and as of spring 2012, it has been closed. In the coming years, this reduction in fishing mortality will lead to a recovery of the West Coast stock to the best possible status given the depleted state of the whole international stock. For the stock in inland waters, a new assessment is presented, in which the dominant contribution from past restocking is put central. Recent changes (increased quantities, shift to west-ward flowing rivers) will have a delayed

effect over the coming 10-20 years. The escapement biomass is expected to decrease until 2020 and then to restore to its current (low) value. Assuming that current conditions (2011) are continued, the impact of the fishery will slowly decline, while the impact of hydropower generation will stabilise/increase, at least until 2030. For the East Coast fishery on silver eel, a new assessment indicates a low mortality on a very large stock of silver eel derived from all over the Baltic. Recent restrictions have reduced the East Coast fishery. Protective actions in the whole Baltic (and their delayed effects) will determine the future trend in the East Coast fishery.

Comparing the overall status of the national Swedish eel stock to the management targets, it is concluded that

1. Criteria of the Swedish Eel Management Plan have been fulfilled almost exactly;
2. Biomass escaping is about one-fourth of pristine escapement, below the minimum target of 40% set in the EU Regulation; and
3. The 2011 anthropogenic impacts are about half the allowable maximum (according to the ICES/WGEEL post-evaluation framework, at one-fourth of pristine escapement). Following the current closure of the West Coast fishery, the impacts will reduce to one-quarter of that allowable maximum.

Sammanfattning

Den europeiska ålen *Anguilla anguilla* (L.) är stadd i stark minskning. EU beslutade 2007 om en förordning med åtgärder för att återställa ålbeståndet i Europa. Förordningen kräver att medlemsstaterna till 2009 skulle ta fram och verkställa nationella ålförvaltningsplaner. Enligt förordningen skall medlemsstaterna till den 1 juli 2012 rapportera till Kommissionen vad som gjorts inom ramen för planen och erhållna resultat vad gäller skydd och återuppbyggnad av ålbeståndet. I föreliggande rapport presenteras en analys och uppskattning av ålbeståndet i Sverige som det såg ut våren 2012, detta med syfte att tjäna som underlag till den svenska uppföljningsrapporten till EU.

I den här rapporten analyseras påverkan på ålbeståndet från fiske, utsättning och dödlighet kopplad till vattenkraft. Andra antropogena effekter, som klimatförändring, miljögifter, spridning av parasiter, eventuella störning av vandring på grund av omflyttning, etcetera har sannolikt också en effekt på ålbeståndet. Sådana faktorer kan svårligen kvantifieras och några relevanta förvaltningsmål har inte heller satts upp. Som en konsekvens av detta och det faktum att den här typen av påverkansfaktorer inte tas upp i EU:s Ålförordning, så är de också exkluderade in denna tekniska utvärdering.

I den här rapporten ligger fokus på kvantifiering av biomassan av blankål som lämnar landet för lek (under faktiska, tänkbara och jungfruliga förhållanden) och på den samlade dödligheten under ålens hela livstid. Resultaten från beståndsanalysen redovisas regionvis, med olika påverkansfaktorer som dominerar i olika områden. När det gäller gulålsfisket längs Västkusten har den uppskattning som gjordes i den svenska Ålförvaltningsplanen extrapolerats till att omfatta även de senaste årens data. Sedan 2009 har det fisket reducerats högst väsentligt och sedan våren 2012 har det stoppats helt. Under kommande år kommer den reduktionen i fiskeridödlighet att leda till en återhämtning av Västkustbeståndet av ål, så långt dagens bristande rekryteringen nu tillåter. För ålen i sötvatten presenteras en ny uppskattning där bidraget från tidigare gjorda

utsättningar dominerar. De förändringar som skett under senare år, i form av ökad mängd utsättningsål och en förskjutning mot vatten på Västkusten, kommer att ge effekt först under de kommande 10-20 åren. Mängden lekvandrande blankål från sötvatten förväntas minska tills 2020 för att sedan återhämta sig till dagens låga nivåer. Förutsatt att nu (2011) gällande förutsättningar inte förändras, så kommer påverkan från ålfisket i sötvatten att långsamt att klinga ut, medan inverkan från vattenkraften stabiliseras eller ökar, åtminstone fram till år 2030. När det gäller fisket efter blankål på Ostkusten, så visar den nya beståndsanalysen på en låg dödlighet i ett väldigt stort bestånd av vandrande blankål härrörande från hela Östersjöbäckenet. Senare års fiskerestriktioner har reducerat ålfisket längs Ostkusten. Skyddsåtgärder i hela Östersjön och deras fördröjda effekt kommer att bestämma den framtida utvecklingen av det ålfisket.

Om man ser till den övergripande statusen av det svenska ålbeståndet, så kan man dra slutsatsen att:

1. Målen för den svenska Ålförvaltningsplanen är i stort uppfyllda,

2. Den mängd blankål som lämnar landet uppgår till ca en fjärdedel av en jungfrulig lekvandring, vilket är lägre än de 40 % som EU:s förordning sätter som en miniminivå, och

3. 2011-års antropogena påverkan är ungefär hälften av vad som maximalt tillåts (enligt ICES/WGEEL ramverk för postevaluering vid en fjärdedel av en jungfrulig lekvandring). Efter det att ålfisket nu stoppats längs Västkusten, så minskar påverkan till en fjärdedel av den tillåtna.

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1 Introduction

1.1 Context and aim of this report

The population of the European eel *Anguilla anguilla* (L.) is in severe decline: fishing yield has declined gradually in the past century to below 20% of former levels, and recruitment has rapidly declined to 1-5 percent over the last three decades (Dekker 2004; ICES 2012). In 2007, the European Union (Anonymous 2007) decided to implement a Regulation establishing measures for the recovery of the stock of European eel (Dekker 2008), obliging EU Member States to develop a national Eel Management Plan by 2009. The common target for all these plans is an escapement of at least 40 % of the silver eel biomass relative to the escapement if no anthropogenic influences would have impacted the stock and recruitment might not have declined. In December 2008, Sweden submitted its Eel Management Plan (Anonymous 2008).

The assessment in this report is technical in nature. The EU Regulation sets targets for the fishery, and for the impact of hydropower generation. Other important factors that might affect the eel stock include climate change, pollution, spread of parasites, and the disruption of migratory behaviour by transport of eels. For these factors, European policies that pre-date the Eel Regulation are in place, such as the Fauna and Flora Directive, the Water Framework Directive and the Common Fisheries Policy. These other policies were assumed to achieve an adequate (or the best achievable) effect for these other impacts; the Eel Regulation has no additional measures. Since this report is focused on an assessment of the eel stock in relation to the implementation of the Eel Regulation, these other factors will remain outside the discussion. This is in line with the approach in the Swedish Eel Management Plan, which does not plan specific actions on these factors. This should not be read as an indication that these other factors might be less relevant. However, the impact of most of these other factors on the eel stock has hardly been quantified. Blending in unquantified aspects into a quantitative analysis jeopardises the assessment, risking a failure to identify a possibly inadequate management of the quantitative factors (fisheries and hydropower mortality).

According to the EU Regulation, Member States will report to the Commission by July 2012, on the implementation of their Eel Management Plans and the effect it has had on stock and fisheries. This report analyses the status of the stock and recent trends in anthropogenic impacts and their relation to the targets set in the EU Regulation and the Swedish Eel Management Plan. The intention is to facilitate the national reporting to the Commission. To this end, time series of monitoring data are presented and stock indicators calculated, fitting the reporting requirements of the EU as laid down in the reporting template supplied by the Commission. Prime focus will be on estimating the biomass of silver eel escaping ($B_{current}$, B_{best} and B_0) and the mortality they endured over their lifetime (ΣA). The three biomass indicators reflect the Swedish contribution to the shared international stock (in current, best achievable and pristine state), and as such, these indicators reflect the status of the stock. However, anthropogenic impacts and most measures to protect and restore the stock have a delayed effect over a range of years (10-20), and for all anthropogenic actions, the historically low recruitment is the ultimately limiting factor. Even if all anthropogenic impacts would be instantaneously reduced to zero (no fishing, no hydropower related mortality, etc), the stock would recover only slowly and would restore to a level below the ultimate target and below the historical level. A substantial recovery of the European stock – and a corresponding increase in recruitment – is required to accomplish the final recovery of the Swedish part of the stock. In contrast, the mortality indicator ΣA measures the anthropogenic impacts in relative terms, comparing the actual impacts to the best achievable (zero impacts) or ultimately sustainable level (A_{lim}). In common words: the biomass indicators ($B_{current}$, B_{best} and B_0) reflect the Swedish contribution to the international stock as constrained by the low recruitment observed all over Europe, while the mortality indicator (ΣA) reflects the anthropogenic impacts and protection levels achieved within Sweden.

The presentation in this report will be technical in nature, and will be focused on the status and dynamics of the stock. Management measures taken, their implementation and proximate effects are not discussed directly, though the related change in anthropogenic impacts will be discussed. A more easy-to-read, descriptive report on the eel stock in Sweden has recently been published, in Swedish and English (Dekker et al. 2011a, b).

1.2 Structure of this report

This chapter continues with a brief introduction to the Swedish eel stock and fishery.

Chapter 2 presents data series on recruitment, catch and landings, restocking and trap & transport of silver eels.

Chapter 3 assesses the anthropogenic impacts on the stock, and the change in impacts related to the implementation of the Eel Management Plan.

Chapter 4 discusses the stock status indicators in relation to the targets set in the EU Regulation and the Swedish Eel Management Plan.

Appendix 1 re-assesses the productivity of inland eel stocks, taking into account the dominating influence of eel restocking.

Appendix 2 re-assesses the impact of hydropower generation plants on out-migrating silver eel, given the results of Appendix 1.

1.3 The Swedish eel stock and fisheries

The eel stock in Sweden occurs from the Norwegian border in the Skagerrak on the west side, all along the coast to about Hälsingland (61°N) in the Baltic Sea, and in most lakes and rivers draining there. Further north, the density declines to very low levels, and these northern areas are therefore excluded from most of the discussions here. In the early 20th century, there were eel fisheries also in the northernmost parts of the Baltic Sea. Current day's distribution covers a multitude of habitat types: along open coasts, in sheltered coastal bays, in fast running rivers and stagnant lakes, in large basins and the smallest creeks, etc. In this report, all of these habitats will be considered. On the next page, we will briefly describe the main habitats and fisheries.

The West Coast from the Norwegian border to Öresund, i.e. 320 km coastline in Skagerrak and Kattegat. Along this open coast there was a fishery for yellow eels, mostly using fyke nets (single or double), but also baited pots during certain periods of the year. The West Coast fishery has been closed as of spring 2012.

Öresund, i.e. a 110 km long Strait between Sweden and Denmark. In this open area both yellow and silver eels are caught using fyke nets and some large pound nets. The northern part of Öresund is the last place where silver eels originating from the Baltic Sea are caught on the coast, before they disappear into the open seas.

The South Coast from Öresund to about Karlskrona, i.e. a 315 km long coastal stretch of which more than 50 % is an open and exposed coast. Silver eels are caught in a traditional fishery using large pound nets.

The East Coast further north, from Karlskrona to Stockholm. Along this 450 km long coastline yellow and silver eels are fished using fyke nets and large pound nets. North of Stockholm, catches exist almost exclusively of silver eels, and the abundance and quantities caught decline going further north.

Inland waters. Eels are found in most lakes, except in the high mountains and the northern parts of the country. Pound nets are used to fish for eel in the biggest lakes Mälaren, Vänern and Hjälmaren, and in some smaller lakes in southern Sweden. In inland lakes, restocking of young eels has contributed to current day's yield, while barriers and dams have obstructed the natural immigration of young eels. Traditional eel weirs (lanefiske) have been operated at several places, and some are still being used. Hydropower generation impacts the emigrating silver eel.

2 Status of stock and fisheries

This chapter focuses on quantities and trends, that is: a description of the prime data series. This includes data series on natural recruitment, on fisheries landings, on restocking of young eels and on Trap & Transport of silver eel. In the next chapter (Chapter 3), these will be related to the size of the stock, and the impact of the anthropogenic actions assessed.
Data series on stock density, growth, cormorant predation, and silver eel quality have been updated in Dekker et al (2011a,b). These data will not be used in the current assessment.

2.1 Natural recruitment

Recruitment of young eels coming from the sea into the rivers is monitored at several sites spread along the southern half of the coasts. At many places, dam owners (frequently hydropower companies) are obliged by the Water Rights Court to facilitate the migration of fish. For the eel, this is often achieved by installing an eel pass with a collecting box at the most downstream dam, manually distributing the catch of young eels over upstream regions. Journals of the catch have been kept, and these data have been used to quantify the recruitment. A typical example of an eel ladder leading into a collecting box is shown in Figure 1.

Figure 1 - Eel ladder and collecting box in the River Mörrumsån. The hydropower station is to the right; immigrating eels climb through the wooden boxes filled with wetted substrate (wetted by pipes), ending in the polyester container on top, from which the eels are collected, weighted and then transported upstream.

Nowhere on the coast do truly unpigmented glass eels enter into Swedish rivers; young yellow eels (bootlace eels) are found instead. However, the nuclear power plant at Ringhals takes in cooling water in front of the coast along the Kattegat, sucking in glass eel too. An Isaacs-Kidd Midwater trawl (IKMWT) is fixed in the current of incoming cooling water, fishing passively during entire nights (Figure 2). The time of arrival at Ringhals varies between the years, probably as a consequence of hydrographical conditions, but the peak in abundance normally occurred in late March to early April. The sampling at Ringhals is performed twice a week in February-April. Sampling also depends on the operation of the power plant and changes in the strength of the current may occur.

Figure 2 Time trend in glass eel recruitment at the Ringhals nuclear power plant on the Swedish Kattegat Coast.

A modified Methot-Isaacs-Kidd Midwater trawl (MIKT) is used from R/V Argos during the ICES-International Young Fish Survey (Hagström & Wickström 1990), (since 1993 called the International Bottom trawl Survey (IBTS Quarter 1). No glass eels were caught in 2008, 2009 and 2010. In 2011 there was no sampling due to technical problems (Figure 3).

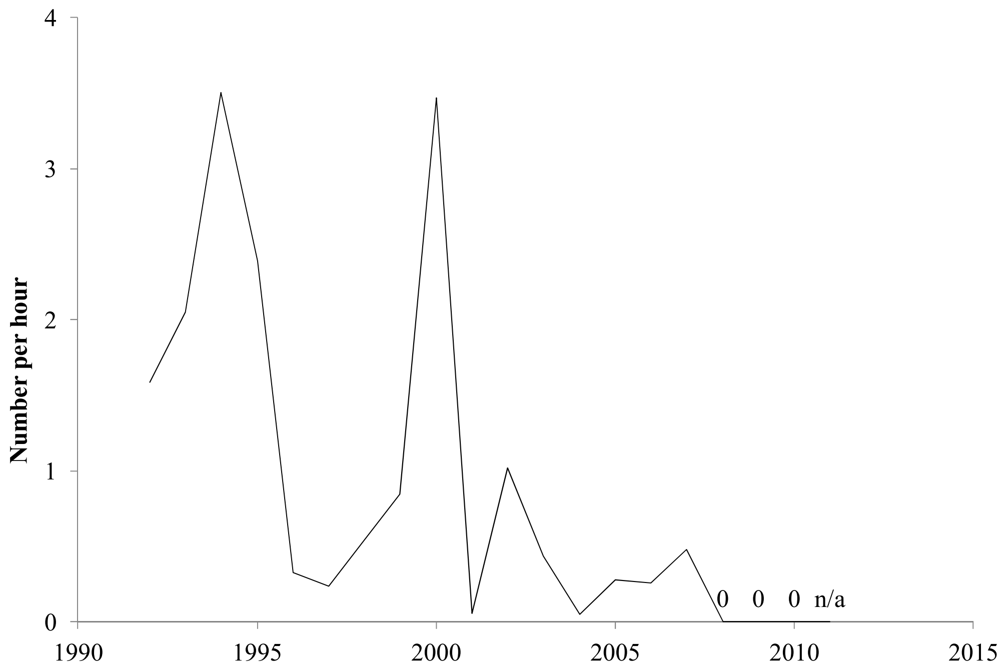


Figure 3 Catch of glass eels (number per hour) by a modified Methot–Isaacs–Kidd Midwater trawl (MIKT) in the Skagerrak-Kattegat 1992–2011. "n/a" = not available.

The eels climbing the ladder in the River Viskan are mostly young eels, which arrived as glass eels on the coast earlier the same year. At all other stations, the eels consist of a mixture of age groups, varying in length from below 15 cm on average in River Göta Älv, to over 35 cm in River Dalälven. Apparently, it takes several years to reach the more northern rivers, and meanwhile, those eels have grown to a larger size.

Figure 4 shows the time series from 1950 onwards, plotted on the map. In recent years, recruitment of young eels has been extremely low and declining at most stations. The normal (linear) scale of Figure 4 seems to suggest that recruitment has now stabilised at a very low level. Looking more closely at the recent data (Figure 5), it turns out that the decline continues at the same rate, declining by ca. 6 % per year on average.

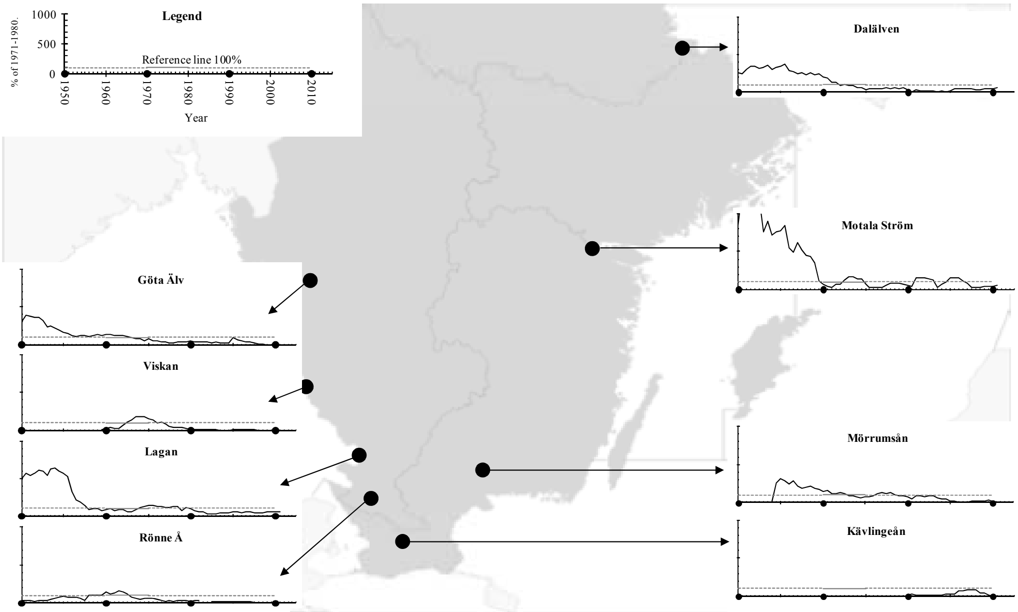


Figure 4 - Recruitment series of young eels immigrating into the rivers. Data are expressed as a percentage of the 1971-1980 mean; moving averages over three years; the vertical scales are linear.

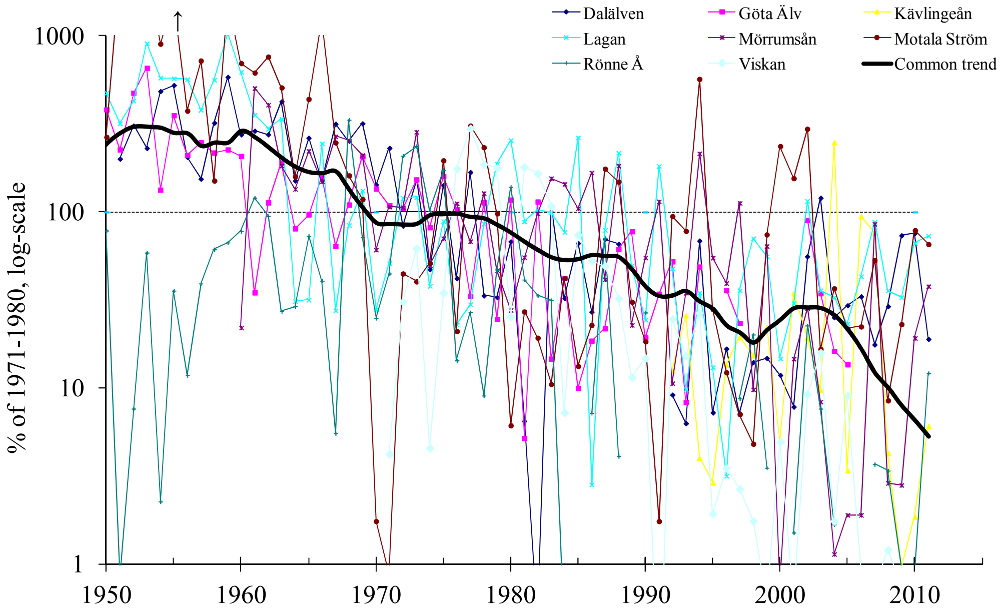


Figure 5 - Recruitment series of young eels immigrating into the rivers for the eight most consistent monitoring sites. Data are expressed as a percentage of the 1971-1980 mean and plotted on a logarithmic scale; no moving average. The common trend is indicated (geometric mean of all series).

2.2 Data on anthropogenic impacts

2.2.1 Catch and landings

Statistics of catch and landings of commercial fisheries have been kept since 1914, but the time series are far from complete, and the reporting system has changed several times. Until the 1980s, statistics were based on detailed reports by fishery officers (fiskerikonsulenter); since that time, sales slips from traders have been collected by the Swedish Statistical Bureau SCB. For the sales slips, the reported county refers to the home address of the trader, not to the location of fishing. In recent years, individual fishers have reported their landings directly to the responsible agencies. Where data series overlapped, precedence has been given here to the more detailed individual reports. For the analysis of the impact of the silver eel fishery along the East Coast, however, a breakdown of landings by county is required for all years. Dekker and Sjöberg (subm.) present the assessment of the impact of the fishery, including a reconstruction of the breakdown by county for the years 1979-1999. Figure 8 shows this reconstruction.

Figure 6 shows the landings from inland waters grouped by county, while Figure 7 shows the same information grouped by lake. Clearly, the total landings from inland waters have declined considerably over the 20th century, but at the same time the landings from the great lakes have increased, now making up more than 75 % of the total inland catches.

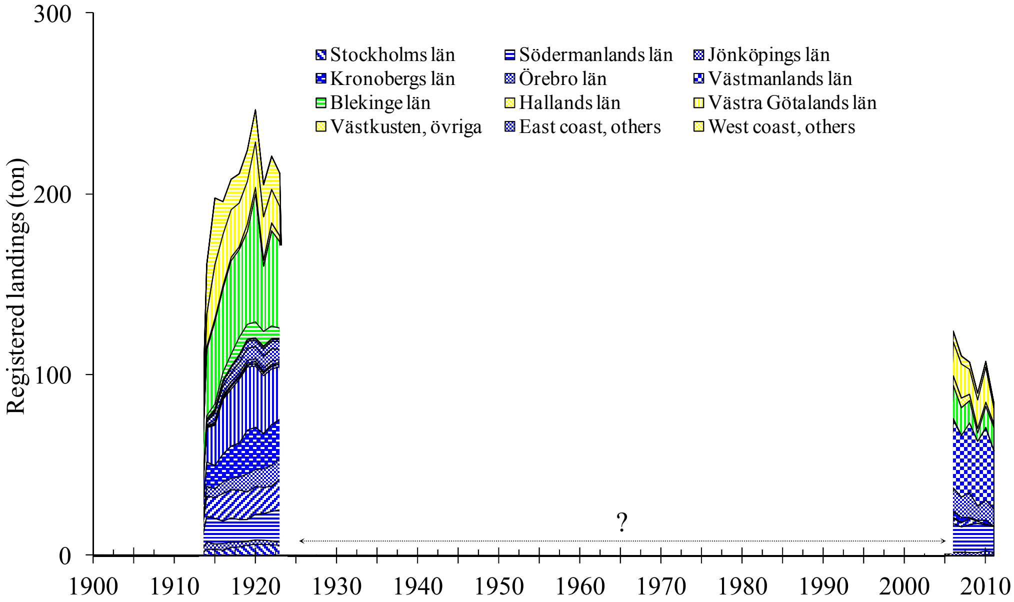


Figure 6 - Landings from inland waters, by county. For the period between 1924 and 2006, no records exist. Note that the vertical scale differs from that in Figure 8.

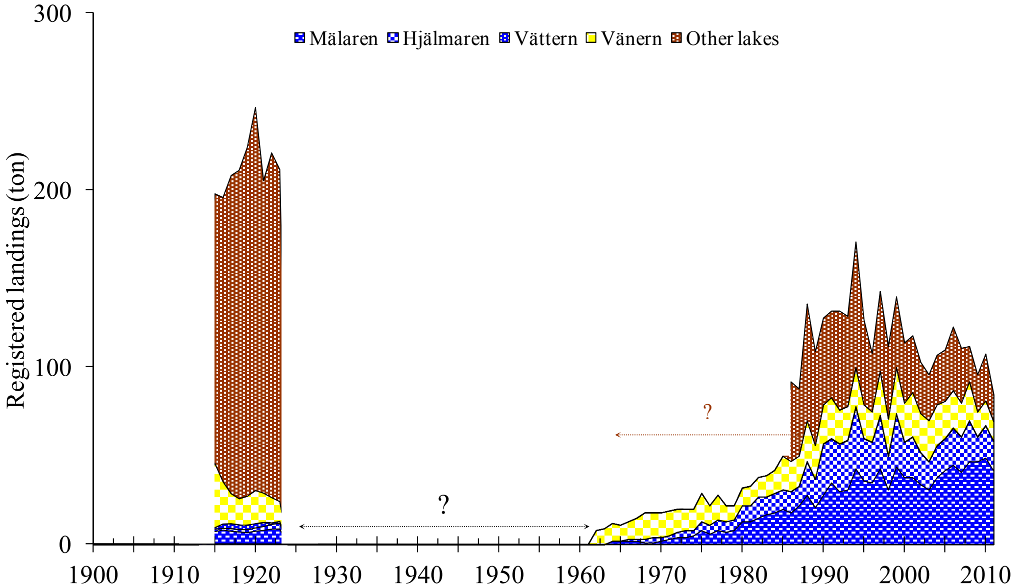


Figure 7 - Landings from inland waters, for each of the great lakes, and for the sum of all smaller lakes. Note that the vertical scale differs from that in Figure 8.

Landings from coastal areas have been nearly ten times higher than those from inland waters in the past, and they are now about five times higher. Figure 8 shows the trend over the 20th century. The decline since the 1950s has been most pronounced on the East Coast and South Coast.

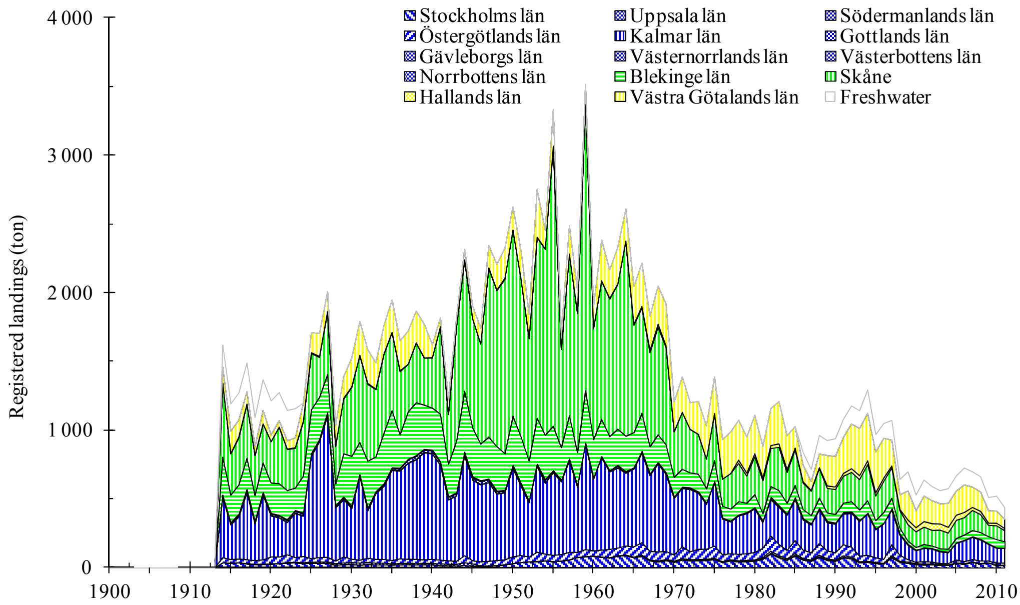


Figure 8 - Landings from coastal waters, by region. Until approx. 1980, statistics were reported by county; since 1999, most fishers report very detailed information. For the years in-between, the break-down per county has been reconstructed. Some counties had such a small catch, that they seem to disappear in the figure; these have been left out from the legend. Note that the vertical scale differs from that in Figure 6 and Figure 7; for comparison, the total inland landings have been added here in grey.

2.2.2 Restocking

Restocking of eels purchased abroad and transport of young eels from one area to another has a long tradition in Sweden. Already in the beginning of the 20th century, eels were imported from England, but it was only since 1950 that a more regular programme was put in place. We report on data from 1950 onwards.

Four different types of restocking material have been applied (Figure 9):

Young eels immigrating into our rivers have been trapped at barriers and transported upstream *within the same river catchment*. Since these eels remained within the river of their own choice, these transports are no further considered.	
Glass eel purchased abroad (elvers, yngel). In the early 1970s, these were imported from France, but later on England was favoured; since 2010, only French glass eels were purchased. The glass eels are quarantined (and fed) in indoor aquaculture facilities; some weeks later, outdoor restocking occurs at an average weight of 1 gr (10 cm length). At the moment of outdoor stocking, they have passed the glass eel stage, and are now fully pigmented elvers.	
Young eels of approximately 5 gr (15 cm length) were trapped in the river Göta Älv near Trollhättan, and transported to other rivers in Sweden for restocking.	
Bootlace eels (sättål) of ca. 90 gr (40 cm length) were caught along the West Coast and transported to the East Coast or inland waters for restocking.	

To enable comparison between these different categories of material, all historical data series have been transformed to a common unit of “glass eel equivalents”, that is: the number of true glass eels, that would be required under natural circumstances to produce the same number of eels of the size actually restocked. The conversion is based on the average size and age of the restocked eels, and the expected number of eels that died between the glass eel stage and the restocking event. Each elver is worth 1.07 glass eel equivalents; each bootlace equals 2.29 glass eel equivalents; and each eel from Trollhättan conforms to 1.32 glass eel equivalents. Figure 9, Figure 10 and Figure 11 (below) are uniformly expressed in these units.

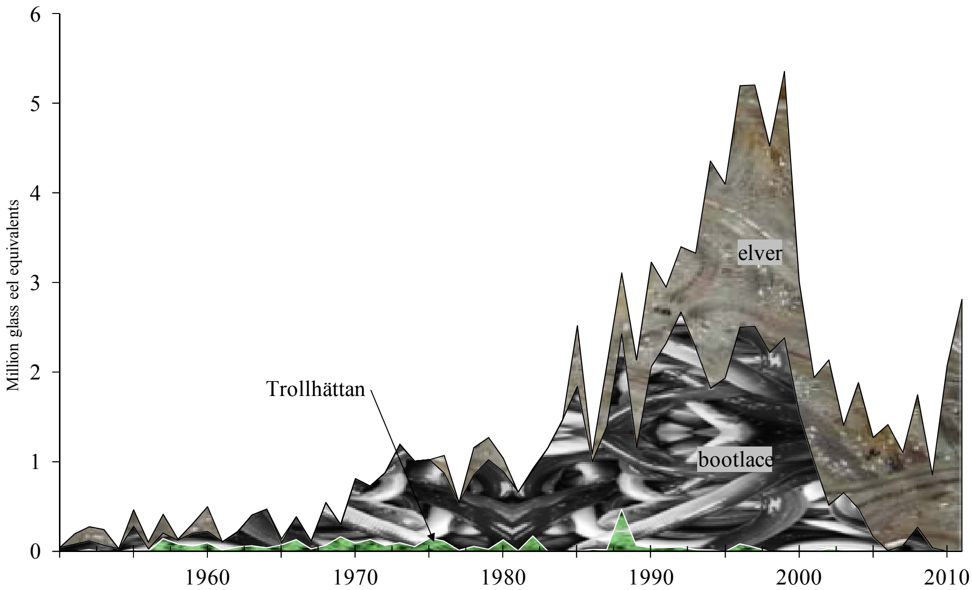


Figure 9 - Quantity and ‘type’ of eel used for restocking since 1950.

Until the 1990s, the transport of eels from the West Coast to the East Coast has dominated the restocking programmes; recently, quarantined glass eel (elver) restocking is the only action left. Trollhättan eel has always been a small quantity, and this transport has ended completely in 2005.

Figure 10 shows the trend in restocking inland lakes and rivers. Until 1970, less than 0.5 million glass eel equivalents were restocked each year. From 1970 to 1990 the quantity gradually increased to 1.5 million per year, reached 2-3 million in the 1990s, and then went rapidly down to about 1 million again. In 2010 and 2011, nearly 2 million equivalents were restocked each year.

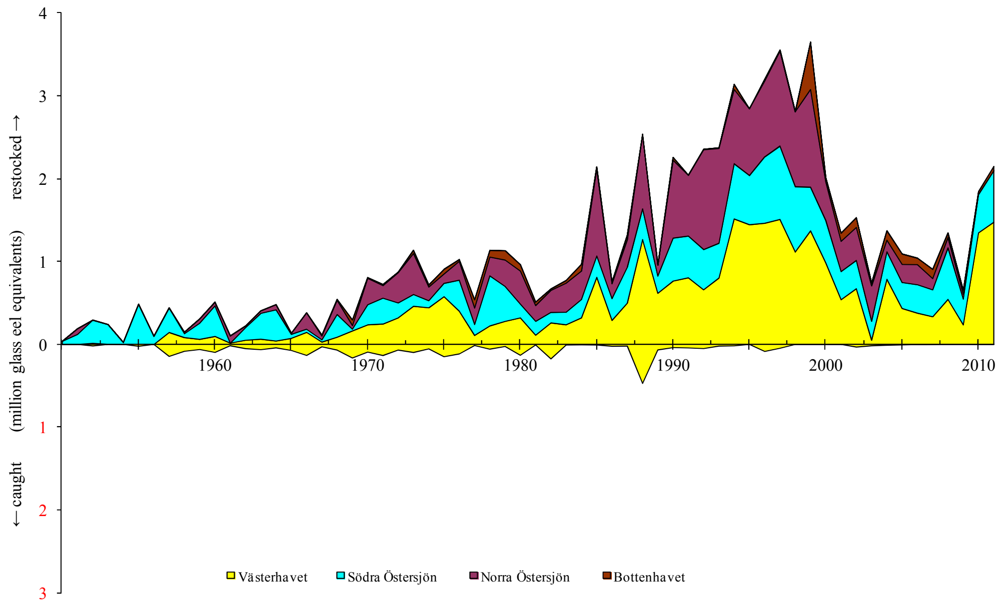


Figure 10 - Restocking in inland waters, by river basin district. Note that the catch of eels for restocking (in fact West Coast only) is shown below the horizontal axis, while release of eels is shown above.

In coastal waters (Figure 11), bootlace eels were caught along the West Coast and restocked along the East Coast. Since 2000, this transport has gradually come to a halt, and net restocking into coastal waters along the East Coast is now small in comparison to the inland restocking.

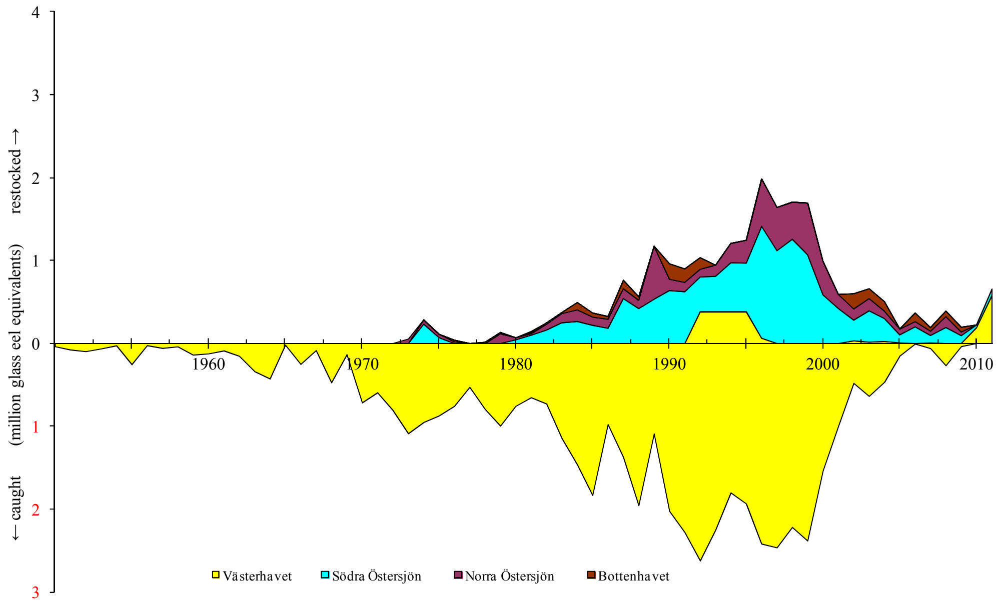


Figure 11 - Restocking in coastal waters, by river basin district. Note that the catch of eels for restocking (in fact West Coast only) is shown below the horizontal axis, while release of eels is shown above.

In the 1990s, eels have been restocked predominantly into the great lakes, in several lakes in southern Sweden, along the East Coast and to a lesser extent in over hundred medium and small lakes (Figure 12). In the 2000s, quantities restocked diminished, especially in the great lakes. In 2010 and 2011, restocking on the East Coast ceased almost completely; restocking inland waters was focused in westward draining lakes, especially Lake Vänern and Lake Vombsjön.

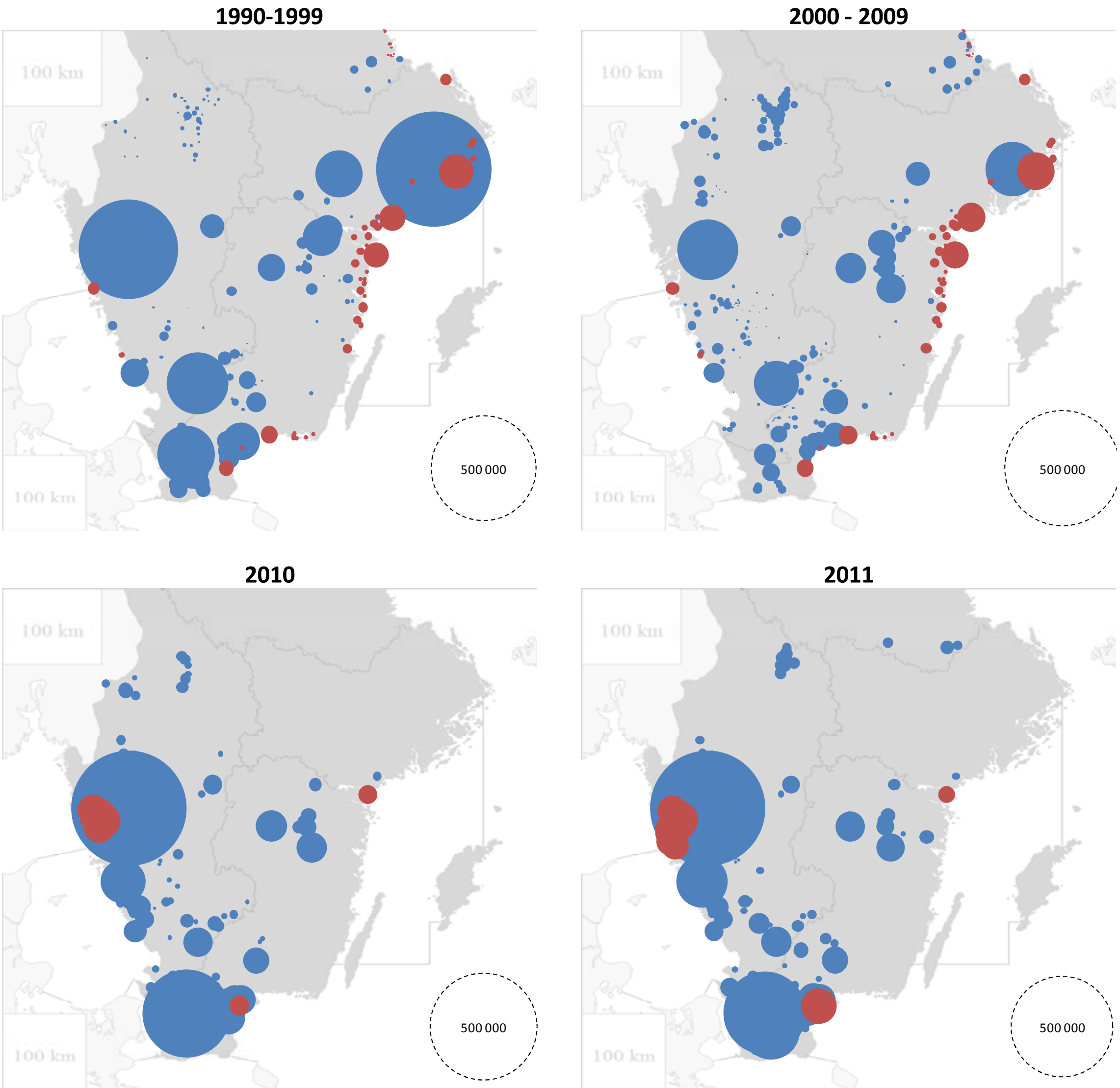


Figure 12 Spatial distribution of the restocking material, for the 1990s, the 2000s and the years 2010 and 2011. Blue: restocking in inland waters; red: restocking along the coast. Restocking north of 61°N (1-2% of the total) is not shown in these maps.

2.2.3 Trap & Transport of silver eel

In early spring 2010, The Swedish Board of Fisheries (Fiskeriverket) and the six largest Swedish hydropower-companies (E.ON, Fortum, Statkraft, Vattenfall, Holmen Energi, Tekniska Verken) have signed a Memorandum of Understanding (Avsiktsförklaring), agreeing that mortality due to hydropower-generation will be reduced, with 40% of the migrating silver eels surviving within 5 years. Within the framework of this agreement, research has been initiated and protective measures have been taken. For the current assessment, Trap & Transport of silver eels caught upstream of power generation plants and released close to river mouths is relevant. The total quantities released in 2011, as reported by the companies involved, sums to nearly 7 ton (Table 1).

The fishery for eels used for Trap & Transport is primarily regulated in accordance with the rules for the commercial fishery. That is: only licensed (or exempted) fishers are allowed to fish, common fishing restrictions apply, and catches made are to be reported in the fishery statistics. This implies that the impact of fishing for Trap & Transport is included in the assessment of the impact of the inland fishery. In practice, however, no catches are reported for some lakes, for which it is known that contributions were made to the Trap & Transport programme. For the time being, not having information to correct, this underreporting is ignored.

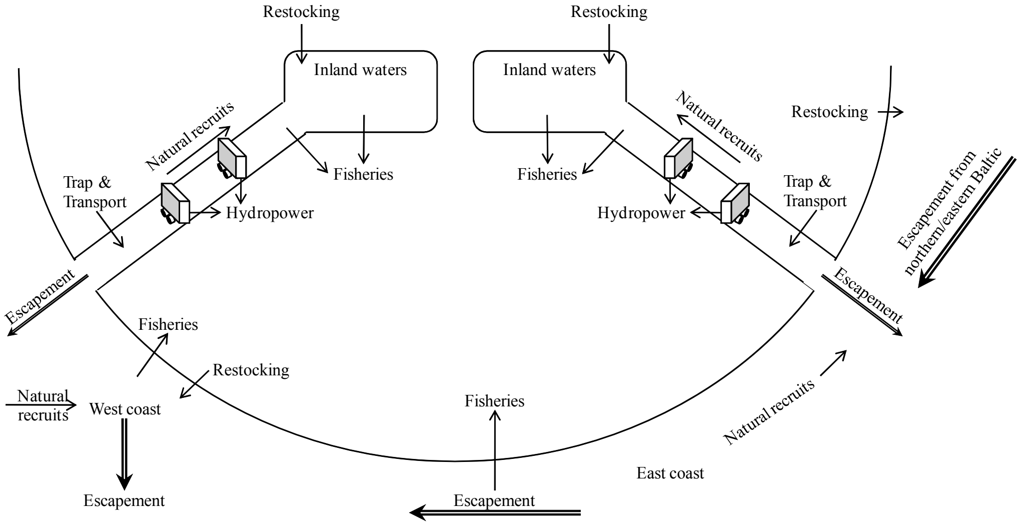
The release of silver eels has a positive effect on the quantity of silver eels escaping, and the quantity released is included as a separate (positive) impact in the current assessment.

Table 1 Quantities of silver eel, trapped/transported/released into river mouths in 2010 and 2011, in biomass (kg) and numbers.

2010	Biomass	Number
Göta Älv	4 650	4 425
Lagan		
Motala Ström		
Mörrumsån		
Total		

2011	Biomass	Number
Göta Älv	4 501	4 250
Lagan	367	653
Motala Ström	676	546
Mörrumsån	1 401	1 220
Total	6 945	6 669

3 Assessment of anthropogenic impacts



According to the Swedish Eel Management Plan, the whole Swedish national territory constitutes a single management unit. Several management actions, however, and most of the anthropogenic impacts differ between geographical areas: inland waters and coastal areas are contrasted and West Coast versus East Coast. Anthropogenic impacts include barriers for immigrating natural recruits, restocking recruits, yellow and silver eel fisheries, hydropower related mortality, Trap & Transport of young recruits and of maturing silver eels; etcetera.

The assessment in this report will be broken down along geographical lines, also taking into account the differences in impacts. This results in four blocks, with little interaction in-between. These blocks are:

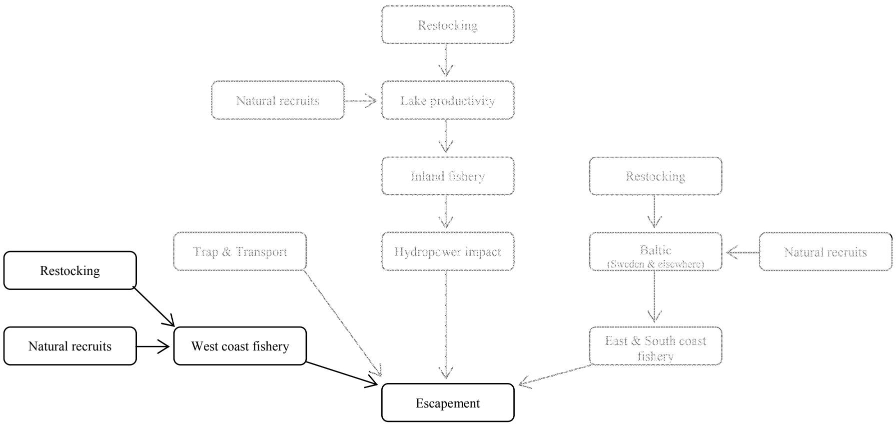
1. West Coast – natural recruitment and restocking, fishery on yellow eel.
2. Inland waters – natural recruitment and restocking, fishery on yellow and silver eel, impact of hydropower generation.
3. Trap & Transport of silver eel – only that.
4. East Coast – natural recruitment and restocking, fishery on silver eel.

For each of these blocks, the delineation from the others will be shortly discussed; following a description of the different impacts, stock indicators will be assessed. Finally, indicators will be derived for the whole national stock in Sweden.

Symbols & notation used in this stock assessment

$B_{current}$	the biomass of silver eel escaping to the ocean to spawn, under the current anthropogenic impacts and current low recruitment.
B_{best}	the biomass of silver eel that might escape, if all anthropogenic impacts would be absent at current low recruitment.
B_0	the biomass of silver eel at natural recruitment and no anthropogenic impacts (pristine state).
A	Anthropogenic mortality per year. This includes fishing mortality F, hydropower mortality H, and other possible factors. A=F+H.
∑A	Total anthropogenic mortality rate, summed over the whole life span.
%SPR	Percent spawner per recruit, that is: current silver eel escapement $B_{current}$ as a percentage of current potential escapement B_{best}.
%SSB	Current silver eel escapement $B_{current}$ as a percentage of the pristine state B_0.

3.1 West Coast



This block comprises all coastal fisheries along the West Coast, north of the Kullaberg. In principle, the fishery on the West Coast could have an impact on the silver eel escaping from inland areas or from the East Coast. Landings data (shown below), however, indicate that silver eel constitute a negligible part of the catch. Anthropogenic impacts in other areas are unlikely to have any impact on the West Coast yellow eel stock.

The assessment of the West Coast fishery presented below is essentially an extrapolation of the results in the Swedish Eel Management Plan to recent years, without change in methods or assumptions.

3.1.1 Recruitment and restocking on the West Coast

Natural recruitment to the West Coast has been monitored (Ringhals nuclear power station, Isaacs-Kidd Midwater Trawl at sea), but this monitoring yields at best an index of recruitment, no estimate of the absolute quantity recruiting to the exploited stock. Restocking of up to 0.4 million glass eel equivalents has been practised in the mid 1990s and almost none in the years following. Since 2009 restocking has increased, up to 0.5 million glass eel equivalents in 2011.

Natural recruits and restocked eel both contribute to the coastal stock, by unknown shares. Hence, there is no quantitative information (absolute or trend) on the total recruitment to the West Coast. The quantities of young eels restocked on the West Coast (Figure 11) have varied between 0 and 0.4 million glass eel equivalents. In 2011, half a million glass eel equivalents were restocked, with a potential production in the order of magnitude of 50 tons some 15 years later. Natural production and other anthropogenic impacts have a much bigger magnitude (see below). Hence, coastal restocking will be included only implicitly in the assessment.

3.1.2 Fishing impact on the West Coast

The West Coast fishery targets almost exclusively yellow eel (Table 2), and the share of silver eel is declining. Tagging experiments on silver eel from the east and south coast have shown only very few recaptures from the West Coast. Since there is no basis to quantify the small impact of the West Coast fishery on the silver eel stock, this impact will be ignored.

Table 2 Landings from the West Coast (Halland and Västra Götaland) by year and life stage, in ton.

Year	Yellow	Silver	Unknown	Total	**Silver %**
2000	147	10	5	161	6
2001	219	6	3	228	3
2002	211	3	3	217	1
2003	189	3	2	194	1
2004	215	2	2	219	1
2005	211	2	2	215	1
2006	235	2	3	240	1
2007	167	3	3	172	2
2008	109	1	58	168	0
2009				107	
2010	108	0	0	108	0
2011	82	0	1	84	0

The Swedish Eel Management Plan estimated the impact of the West Coast yellow eel fishery (Appendix 5) at $F=0.31$ per annum, corresponding to $\Sigma A=2.33$. Since 2009, the West Coast fishery has been restricted, and since spring 2012, the fishery has been closed completely.

Past catch sampling (Dekker et al. 2011, Figure 26) indicates that up to ten different age groups were simultaneously represented in the catch, six age groups dominating. The fishing restrictions implemented in 2009 will have had first effects in 2009, but full effect is not expected before 2019 - ten years after the implementation of the restriction, when even the oldest age group at that time has been exploited by the restricted fishery throughout its whole life. Additionally, the minimum legal size (37 cm) has been raised in 2007 (40 cm) and again in 2011 (45 cm), affecting foremost the youngest age groups in the catch, which are exactly the age groups affected only by the restricted fishery. That is: the situation during the reporting years is dominated by transient effects, and only little change is expected by 2011.

Transient effects in a fishery that has been closed since – a proper assessment of the implementation of the Eel Management Plan will be very hard to make. The analysis of length-frequency data in the Swedish Eel Management Plan has therefore not been repeated and extended to cover the transient effects. Only a simple extrapolation from the earlier results is analysed here.

During the years 2009-2012, the ongoing decline of the recruitment and stock will have continued, while the restrictions on the yellow eel fisheries might have increased the yellow eel stock being exploited. To simplify the assessment during the years of transition, it is assumed that the stock at large has remained more or less stable, while the restrictions on the fishery have led to the observed reduction in catches. The Swedish Eel Management Plan took 2006 as its baseline for assessment; over the years 2000-2006 (6 age groups dominating the catch), the landings from the West Coast were 210 ton per year on average. For 2000-2006, the Swedish Eel Management Plan estimated the lifetime fishing mortality ΣA at 2.33[1]. In Table 3, the trend in fishing mortality is estimated on the basis of the assumed

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[1] Appendix 5 of the Eel Management Plan 2009 lists for the West Coast: Growth=45 mm/a. Natural mortality M=0.0051/mm, 0.23/a. Fishing mortality F=0.0069/mm, 0.3105/a. Length at silvering = 65 cm. Using a standard Beverton & Holt type age-structured model (Dekker et al. 2008), this can be shown to correspond to $\Sigma A_{yellow} = 2.33$.

proportionality between fishing mortality and landings, showing a decline in impact from approximately $\Sigma A = 2.3$ before 2006 to $\Sigma A = 0.9$ in 2011. The full closure of the fishery by 2012 will bring the fishing mortality to zero.

Table 3 West Coast fishery: reported landings (ton) and estimated fishing mortality (rate) in the yellow eel stage ΣA_{yellow} by year, extrapolated from the 2006 assessment.

Year	Landings	ΣA_{yellow}
1999	247	2.74
2000	161	1.79
2001	228	2.53
2002	217	2.41
2003	194	2.15
2004	219	2.43
2005	215	2.39
2006	240	2.66
2007	172	1.91
2008	168	1.86
2009	107	1.19
2010	108	1.20
2011	84	0.93
2012	0	0

3.1.3 West Coast stock indicators

Average reported landing between 2000 and 2006 was 210 ton (1.2 million eels); fishing mortality in 2006 was estimated at 0.31. Using a standard Beverton & Holt type age-structured model (Dekker et al. 2008), this can be shown to correspond to $B_{current}$ = 12 ton (0.02 million eels) and B_{best} = 1 154 ton (1.7 million eels). Following the closure of the fishery by spring 2012, it is expected that $B_{current}$ slowly converges to B_{best} over a range of ten years, though the general stock decline will be superimposed. The first years, $B_{current}$ will be close to its current low value of 12 ton.

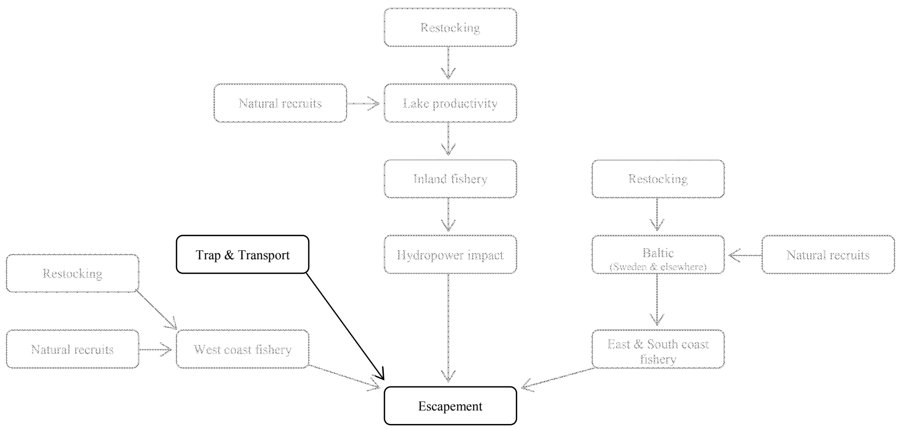
The biomass of the pristine stock B_0 is difficult to quantify. Since the 1950s, landings first went up from 197 ton to 280 ton in the 1990s, to decline to 190 ton in the 2000s eventually. Meanwhile, recruitment in nearby rivers has declined to approximately 10% of its 1950s value. To derive an estimate of B_0, B_{best} can be scaled either in proportion to the landings, or in proportion to the incoming recruitment. Scaling B_{best} according to the landings (assuming a constant fishing mortality), the pristine stock is estimated at B_0 = 1 154 ton, but scaling B_{best} according to recruitment, the pristine stock becomes B_0 = 11 540 ton and historical fishing mortality must have been in the order of F=0.005. Reality will have been somewhere in-between these two extremes. However, the estimate for $B_{current}$ is 12 ton – that is 1% or 1‰ of either of the estimates of B_0. Running ahead of the discussion on limit reference points in section 4.2, the limit for lifetime anthropogenic mortality ΣA comes at ${}^{1\%}/_{40\%} \times 0.92 = 0.0230$ or ${}^{1‰}/_{40\%} \times 0.92 = 0.0023$, while the actual value is 0.9300 (see ICES 2011, section 3.6 for details of the calculation of the limit). The uncertainty on B_0 appears to be almost irrelevant – to come within sustainable limits, a major reduction in fishing impact is required anyhow. In the remainder of this report, it will be assumed that B_0 = 1 154 ton and $B_{current}$ / B_0 = 1%; the alternative assumption would require extending the axes of all plots considerably, without adding information. It should be noted that this is a purely pragmatic consideration, not a value judgement.

Estimates of lifetime mortality ΣA by year are given in Table 3, based on an assumed proportionality between landings and mortality. It should be noted that these estimates concern the yellow eel stage only. When the stock recovers from its recent high fishing mortality, a larger stock of silver eels will result, and potential mortality in the silver eel stage will gain importance. However, the whole fishery being closed by spring 2012, the future fishing impact on the silver eel will be nil too.

The closure of the West Coast fishery by spring 2012 brings the fishing mortality to zero immediately, but it will take up to ten years before the silver eel escapement will have recovered. The recent change in management of this fishery having a delayed effect, a medium-term projection of the stock indicators is required. To keep this simple, it is assumed that $B_{current}$ converges linearly to B_{best} over a range of ten years. This simplified assumption does hardly affect the stock indicators for the West Coast (the fishery is closed and the stock recovers), but it does have a marginal affect on the stock indicators for the country as a whole; see chapter 4.

The assessment of the West Coast fishery given above follows the lines of the Swedish Eel Management Plan, and extrapolates those results to recent years. The assessment presented in Dekker et al. (2011a,b) deviates in two aspects: first, the current assessment focuses on the year 2011, while Dekker et al. focused on 2006. Secondly, the assessment in the Swedish Eel Management Plan (which was copied by Dekker et al 2011a,b) assumed a knife-edge maturation of the silver eel, that is: all eels were assumed to mature to the silver eel stage at a length of 65 cm exactly. In the current assessment, a more realistic gradual silvering pattern (a logistic maturation ogive) has been used, resulting in a lower estimate of $B_{current}$ and a higher estimate of B_{best}.

3.2 Trap & Transport of silver eel



Though the above diagram may suggest otherwise, Trap & Transport has been executed in rivers flowing to the West Coast and East Coast alike.

The quantity of silver eels in the West Coast fishery is negligibly small. Hence, the impact of the West Coast fishery on the silver eels released at the coast can be safely ignored. Trap &

Transport itself has no impact on other areas. The fishery for this programme is included in the assessment of the inland stock.

3.2.1 Trap & Transport indicators

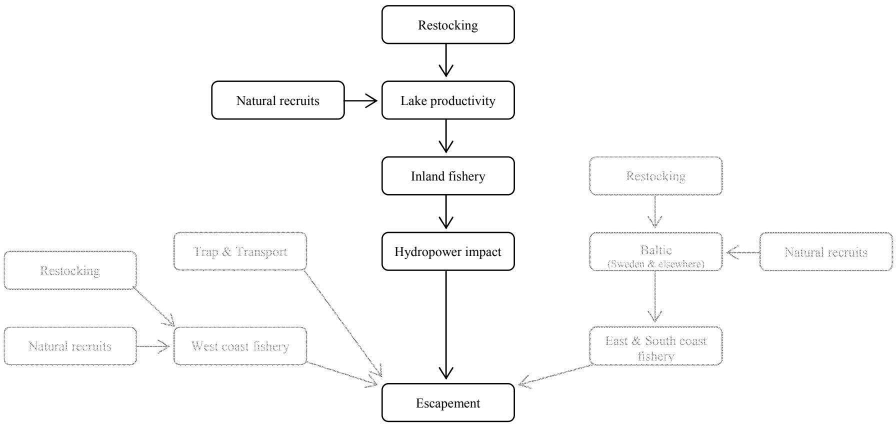
Current escapement $B_{current}$ related to the Trap & Transport programme is simply the quantity of silver eels being released, i.e. $B_{current}$ = 7 ton. Without anthropogenic intervention, no silver eels would have been released, i.e. B_{best} = 0 ton. And likewise, under pristine circumstances, no silver eels would have been released, i.e. B_0 = 0 ton.

The 'mortality' of the Trap & Transport programme is undefined. In technical terms, $\Sigma A = -\ln(B_{current} / B_{best})$, which is undefined for B_{best}=0. In practical terms, the Trap & Transport programme cannot be compared to the stock it is affecting, since the release of silver eels is not uniquely affecting a specific part of the stock (which would have been the 100%). Combining the various stock indicators for the whole of Sweden (below), the effect of the Trap & Transport programme will contribute to the national stock, and in that context, it will be expressed as a percentage of the total escapement.

The quantity $B_{current}$ = 7 ton corresponds to 6 669 silver eels.

Trap & Transport has begun in 2010; it is not discussed in the Swedish Eel Management Plan. The effect of Trap & Transport on silver eel escapement is immediate; no delayed effects occur. For the medium term projections discussed in chapter 4, it has been assumed that future Trap & Transport continues at its current low level.

3.3 Inland waters



This block comprises all inland waters, whether draining into the Baltic, into the Sounds or the Skagerrak/Kattegat area. In principle, the fishery on the West Coast could have an impact on the silver eel escaping from inland areas. Landings data, however, indicate that silver eel constitute a negligible part of that catch. The fishery on the East Coast does have an impact on silver eels escaping from rivers draining eastward, but the impact of the East Coast fishery is very small in comparison to the anthropogenic impacts in inland waters themselves. On the other hand, these anthropogenic impacts in inland waters do reduce the escapement of silver eels towards the East Coast considerably, which affects the assessment on the East Coast, as discussed in section 3.4, below.

In this section, a new assessment of the inland eel stock is presented. The line of thinking of the Swedish Eel Management Plan in calculating impacts is followed, but the starting point is the restocked quantities of eel rather than lake productivity. For the assessment of the impacts of fishing and hydropower generation, the methods and assumptions used in the Swedish Eel Management Plan have been copied without further change.

3.3.1 Recruitment and restocking in inland waters

Recruitment to inland waters has been monitored for decades, and eight long-running series are continued. At most places, young ascending eels are captured below a migration barrier and transported upstream. The quantity caught and transported most likely represents the actual recruitment to those rivers. Elsewhere, unknown quantities of young eels recruit. Additionally, glass eels purchased abroad have been restocked, and young eels have been redistributed over the country (often from the West Coast to the East Coast and into inland waters). All in all, it is unclear how the quantities of natural recruits, of redistributed young eels and of imported glass eels relate. In Appendix 1, an analysis is presented relating known fishing yields to restockings and habitat productivity. This analysis shows that the data are inconclusive. Since the vast majority of the catch of the commercial fishery consists of eels of restocked origin, this assessment will give precedence to the relation between yield and earlier restocking.

3.3.2 Fishing impact in inland waters

The inland fishery targets both yellow and silver eel. The share of yellow eel in the total landings is very small (Table 4). In accordance with the Eel Management Plan, the impact of the yellow eel fishery in inland waters will be lumped with that of the silver eel fishery, and only one estimate of the impact given. Most yellow eels in the catch have a size and age close to that of the silver eel.

Appendix 2 presents an analysis of the relation between quantities restocked in the past and resulting fishing yield. The analysis indicates that the ratio of actual yield to predicted production for the lakes for which landings data are available (Mälaren, Vänern and Hjälmaren) is currently surprisingly high, rather far above the level predicted by conventional production models. The inevitable conclusion is that natural mortality M must have been low, below the values ordinarily assumed. Table 5 (nedan) presents estimates for $M=0.05$ and $M=0.10$, that is: a low and a high level for the data at hand – though both are considerably below conventionally assumed values. Results indicate that the assumed level of natural mortality influences the absolute magnitude of the calculated fishing impact, but not the trend: for both values of M, a declining trend in fishing mortality is shown, most recent F being approximately half the mid-2000s value.

Table 4 Inland fishery: Landings by year and life stage, in ton.

Year	Yellow	Silver	Unknown	Total	**Yellow %**
2010	2.259	105.474	0	107.733	2
2011	1.126	83.4603	0	84.5863	1

Table 5 Inland fishery: production as predicted from past restocking and reported landings (in ton) and estimated fishing mortality ΣA by year (rate), for two values of natural mortality M.

		M=0.05		M=0.10	
Year	Catch	Predicted production	Fishing mortality F	Predicted production	Fishing mortality F
2000	114	300	0.48	172	1.09
2001	118	321	0.46	181	1.06
2002	103	332	0.37	184	0.82
2003	96	344	0.33	188	0.71
2004	107	355	0.36	191	0.82
2005	110	362	0.36	193	0.84
2006	123	384	0.39	204	0.93
2007	111	417	0.31	219	0.71
2008	112	463	0.28	239	0.63
2009	96	500	0.21	255	0.47
2010	108	542	0.22	271	0.51
2011	85	576	0.16	280	0.36

3.3.3 Impact of hydropower generation plants

Appendix 2 presents an analysis of the production, as expected from past restocking of young eels. In section 3.3.2 above, the impact of the fishery in inland waters is assessed, essentially comparing the reported fishing yield to this predicted production. Subtracting the observed catch from the calculated production, what is left is a quantity of silver eels that migrates out towards the sea. That is the quantity of silver eels potentially impacted by the hydropower generation. The Swedish Eel Management Plan estimates the quantity actually being killed using information on the quantity of eels being impacted, an average impact per hydropower station of 70% and the known location and number of hydropower stations. Appendix 2 follows this approach. As for the fisheries (above), estimates are presented for a low (left) and high (right) assumption on natural mortality M. Unlikely for the fisheries, results for the impact of hydropower indicate (Table 6) that the assumed value of natural mortality M does not so much influence the absolute mortality level, but the trend over the years: at low natural mortality, the trend in recent years is less pronounced, though both show a minimum in the mid-2000s, and an increase later-on. At low natural mortality, however, survival from restocking to silver eel is about twice as high compared to high natural mortality (e.g. in 2011, 576 ton production compared to 280 ton), and the quantity of eels impacted by hydropower is more than doubled (e.g. in 2011, 326 ton compared to 138 ton).

Table 6 Hydropower impact on inland stocks: production as predicted from past restocking and reported landings (in ton) and estimated impact of hydropower by year (expressed as biomass and mortality rate H) for two values of natural mortality M.

	M=0.05					M=0.10				
				Hydro power					Hydro power	
Year	Predicted production	Catch	Production min catch	Quantity	mort. H	Predicted production	Catch	Production - catch	Quantity	mort. H
2000	300	114	186	118	1.01	172	114	58	34	0.90
2001	321	118	203	114	0.83	181	118	63	28	0.59
2002	332	103	229	115	0.69	184	103	81	30	0.47
2003	344	96	248	107	0.56	188	96	92	26	0.34
2004	355	107	248	93	0.47	191	107	84	17	0.22
2005	362	110	252	88	0.43	193	110	83	15	0.20
2006	384	123	261	89	0.42	204	123	81	12	0.16
2007	417	111	306	126	0.53	219	111	108	35	0.39
2008	463	112	351	176	0.69	239	112	127	61	0.65
2009	500	96	404	229	0.84	255	96	159	94	0.91
2010	542	108	434	266	0.95	271	108	163	105	1.04
2011	576	85	491	326	1.09	280	85	195	138	1.22

3.3.4 Inland stock indicators

The assessment of the inland stock presented here is based on relatively little information. Time series of landings statistics are incomplete, direct monitoring of the stock has not yet been analysed, and the impact of both the fishery and of hydropower generation has not been ground-truthed. The impact assessment provided above (and in more detail in Appendix 2) is based on recorded quantities of eel being restocked, to which a conventional stock dynamics model is applied. The outcome can only be verified against the incomplete landings statistics, and this indicates that an unexpected low natural mortality level applies. Appendix 2 presents detailed results for a low and high assumption on natural mortality M - both considerably below values assumed conventionally. For B_0, the current production based on restocking is of no relevance. In the 1920s, the commercial catch was in the order of 200 ton. Assuming that fishing mortality at that time was in the same order of magnitude as today's ($F \approx 0.5$ at

M=0.05; F≈1.0 at M=0.10), an estimate of the historical biomass of silver eels before fishing comes at 500 resp. 300 ton.

A summary of stock indicators for the year 2011 is given in Table 7. The trend in anthropogenic mortalities is summarised in Table 8. Current restocking will have a delayed effect on stock indicators, at least up to 2030. Medium term projections, as detailed in Appendix 2, have been included in the country-wide stock indicators discussed in chapter 4.

The catch of 85 ton conforms to approximately 0.12 million silver eels.

Table 7 Comparison of inland stock indicators, assuming a low (left) or high (right) natural mortality M. Note that in this table, B_{best} comprises primarily restocked eels, while B_0 represents the notional pristine stock without restocking.

Year = 2011	M=0.05	M=0.10	unit
Production, B_{best}	576	280	ton
Production, N_{best}	0.92	0.46	million
Fishery Catch	85	85	ton
Fishery Catch	0.12	0.12	million
Fishery mortality F	0.16	0.36	rate
Hydropower quantity	326	138	ton
Hydropower quantity	0.58	0.26	million
Hydropower mortality H	1.09	1.22	rate
Escapement, $B_{current}$	165	58	ton
Escapement, $N_{current}$	0.22	0.08	million
Pristine escapement, B_0	500	300	ton
Pristine escapement, N_0	0.80	0.49	million

Table 8 Inland stock: time trends in fishing and hydropower mortalities (rates), assuming a low (left) or high (right) natural mortality M.

	M=0.05			M=0.10		
Year	Fishing mortality F	Hydropower mortality H	Total ΣA	Fishing mortality F	Hydropower mortality H	Total ΣA
2000	0.48	1.01	1.49	1.09	0.90	1.99
2001	0.46	0.83	1.29	1.06	0.59	1.65
2002	0.37	0.69	1.07	0.82	0.47	1.30
2003	0.33	0.56	0.89	0.71	0.34	1.05
2004	0.36	0.47	0.83	0.82	0.22	1.04
2005	0.36	0.43	0.79	0.84	0.20	1.04
2006	0.39	0.42	0.80	0.93	0.16	1.09
2007	0.31	0.53	0.84	0.71	0.39	1.10
2008	0.28	0.69	0.97	0.63	0.65	1.28
2009	0.21	0.84	1.05	0.47	0.91	1.38
2010	0.22	0.95	1.17	0.51	1.04	1.55
2011	0.16	1.09	1.25	0.36	1.22	1.58

3.3.5 Restocking and stock indicators

The inland stock indicators given above do in general conform to the approach taken in the Swedish Eel Management Plan. The estimate of B_{best}, however, only considers the contribution from restocking; noting that approx. 10% of the commercial catch consists of natural recruits, an extra margin of 10% might have to be added to the estimate of B_{best} - though that is only a small correction in comparison to the uncertainty in the estimate itself.

However, the interpretation of B_{best} is ambiguous: for some purposes it should include restocked eels, for others it should not.

The concept of B_{best} was coined by Dekker (2010), introducing B_{best} in a table of stock indicators, but not giving an exact definition. Subsequently, ICES (2010) adopted the assessment framework proposed by Dekker (2010), adding definitions of the indicators in a glossary, including B_{best} (the sentence appears to be open ended):

Best achievable biomass (B_{best})	Spawning biomass corresponding to recent natural recruitment that would have survived if there was only natural mortality and no restocking; that is

ICES (2011 and 2012) applied the same concepts, without changing the definition. Finally, the template for the 2012 post-evaluation supplied by the EU Commission quotes:

B_{best} The amount of silver eel biomass that would have existed if no anthropogenic influences had impacted the current stock.

The estimates of B_{best} given above, however, are almost exclusively based on restocked eel. Applying a more rigorous definition of B_{best} for the inland waters in Sweden, one should assess the amount of silver eel that would have been produced from inland waters, if there had been no restocking, no fishery, no impact of hydropower generation, but also no obstacles to immigration of young recruits. Especially the latter factor is hard to assess, since it refers to a situation that has not been observed for decades. Without migration barriers, a larger share of the national stock could have immigrated into inland waters, which would have affected both the stocks in inland and coastal waters.

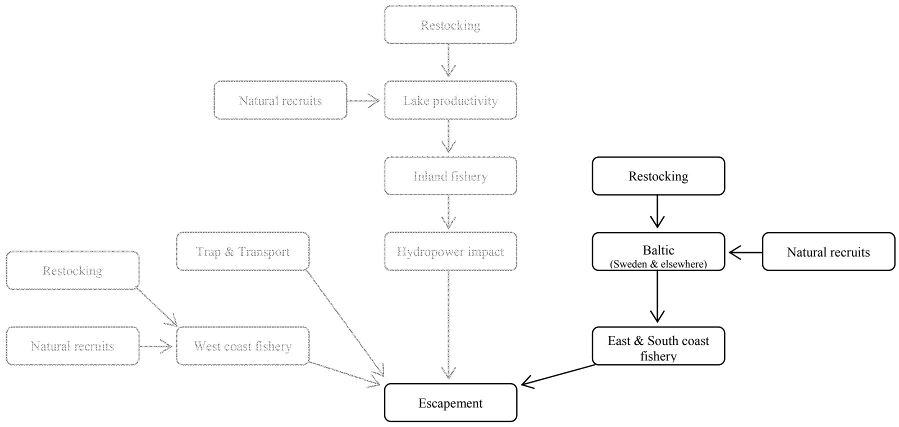
The rationale behind the concept of B_{best} (and ΣA) is to quantify the natural conditions, despite the fact that current opportunities are severely restricted by the low recruitment coming in. B_0 is the silver eel biomass under historical, high recruitment, quantifying the full potential under historical high recruitment (though even at that time, recruitment has probably been the limiting factor; Schmidt 1906). The ratio $B_{current}/B_{best}$ (known as %SPR) indicates to what extent current opportunities to protect the stock are exploited to the max; the ratio B_{best}/B_0 quantifies the external restrictions due to low recruitment coming in; and finally the ratio $B_{current}/B_0$ quantifies the actual status of the stock, relative to pristine conditions. The latter is the indicator used for setting targets in the EU Eel Regulation.

Define B_{best}^{+} to be an estimate of B_{best} that includes the biomass derived from restocking and B_{best}^{-} the same without restocking. The ratio $B_{current}/B_{best}^{+}$ now indicates to what extent the currently available stock is affected by anthropogenic impacts other than restocking, while $B_{current}/B_{best}^{-}$ quantifies the relative contribution from the Swedish inland stock to the international stock recovery taking into account the currently depleted state of the international stock. For international comparison between management areas, $B_{current}/B_{best}^{-}$ is the preferred indicator, reflecting the (positive) effect of restocking via $B_{current}$. The Swedish Eel Management Plan, however, sets its objectives and targets so as to protect wild and restocked eels alike, which corresponds to $B_{current}/B_{best}^{+}$.

The estimate of B_{best} given above is based on restocking only – i.e. ($B_{best}^{+} - B_{best}^{-}$); it is argued that B_{best}^{-} is just 10% × B_{best}^{+}. Hence, the stock indicators listed in Table 7 match the Swedish Eel Management Plan - but for international comparison, the contribution from restocking needs careful re-consideration.

Finally, restocking might also affect the estimate of B_0, the biomass escaping under pristine conditions of no anthropogenic impacts and historically high recruitment. Clearly, the notion of B_0 does not include restocking (Table 7). To be consistent with the approach in the Swedish Eel Management Plan (protecting wild and restocked eels alike), however, the contribution from the inland stock to the national stock indicators (Section 3.5, Table 12, below) will be calculated here as the sum of the notional pristine stock plus the recently added restocking.

3.4 East Coast



This block comprises the coastal fisheries in the Baltic proper and in the Sounds, north up to Kullaberg. This area is labelled here as East Coast, though it does include the area that is often called South Coast too. For assessment purposes, this is a reasonably homogenous area.

The fishery on the East Coast has an impact on the eels escaping from inland waters draining to the east/south. Below, it will be shown that this impact is negligibly small in comparison to the anthropogenic impacts in those inland waters.

The silver eel stock migrating along the East Coast is derived from yellow eel stocks across the Baltic, probably including inland and coastal habitats alike. The current assessment is restricted to the Swedish territory, the impact of Swedish fisheries. As such, this constitutes a partial assessment, only covering the migratory phase (and the yellow eel stock in Swedish coastal waters).

The assessment of the East Coast fishery presented below is based on a recent in-depth analysis of a century of mark-release-recapture experiments (Dekker and Sjöberg subm.). Most recent mark-recapture results (2006-2008) are subsequently extrapolated to current years. The methods and assumptions used deviate considerably from those used in the Swedish Eel Management Plan.

3.4.1 Recruitment and restocking on the East Coast

Natural recruitment to the East Coast has not been monitored (open coastal habitats). Restocking of up to 1.5 million glass eel equivalents has been practised until the year 2000, but quantities have declined, and coastal restocking has ceased almost completely by 2010.

Natural recruits and restocked eel both contribute to the coastal stock, by unknown shares. Hence, there is no quantitative information (absolute or trend) on the total recruitment to the East Coast. The quantities of young eels restocked on the East Coast (Figure 11) have varied between 0 and 2 million glass eel equivalents. In 2011, less than 0.1 million glass eel equivalents were restocked, with a potential production in the order of magnitude of 10 tons some 15 years later. Natural production and other anthropogenic impacts have a much bigger magnitude (see below). Hence, the coastal restocking will be included only implicitly in the assessment.

3.4.2 Fishing impact on the East Coast

The East Coast fishery targets both yellow and silver eel. The share of yellow eel in the total landings is small and declining (Table 9). Analysis of samples from the yellow eel fishery, as reported in the Swedish Eel Management Plan, give erratic results: the estimated fishing mortality reported in Appendix 5 of the Eel Management Plan for the East Coast fishery exceeds the estimate for the West Coast fishery. In accordance with the Eel Management Plan, the impact of the yellow eel fishery on the East Coast will be lumped with that of the silver eel fishery, and only one estimate of the impact given.

Table 9 East Coast fishery: Landings by year and life stage, in ton.

Year	Yellow	Silver	Unknown	Total	**Yellow %**
2000	45	201	10	256	18
2001	43	246	6	295	15
2002	45	222	5	272	17
2003	39	232	3	274	14
2004	35	214	2	251	14
2005	37	303	6	345	11
2006	37	317	10	364	10
2007	36	368	13	417	9
2008	22	266	97	385	6
2009				309	
2010	28	271	7	307	9
2011	29	239	3	271	11

Dekker & Sjöberg (subm.) analyse the impact of the fishery at the East Coast on the silver eel, reporting an estimated mortality of ca. 0.1, averaged over the years 2000-2009. This estimate is primarily based on two tagging experiments, in 2006 and 2008 respectively, when reported landings amounted to 366 resp. 389 ton. In recent years, no new tagging experiments have been executed; no trend in fishing mortality can be assessed. Starting in 2009, however, a reduction in fishing impact has been implemented, and reported landings have fallen to 271 ton in 2011.

Since the implementation of the Eel Management Plan, the ongoing decline of the stock will have continued, while the restrictions on the yellow eel fisheries in inland and coastal habitats might have increased the stock of silver eels at large. In the absence of further evidence, it is assumed that the stock at large has remained stable over the recent years, while the restrictions on the silver eel fishery have led to the observed reduction in catches. Noting the relatively low absolute mortality (F=0.1), this implies that fishing mortality and landings will be proportional. In Table 10, the trend in fishing mortality is estimated on the basis of this assumed proportionality, showing a decline in impact from approximately F = 0.10 to F = 0.075 since the implementation of the Eel Management Plan.

Table 10 East Coast fishery: reported landings, number of tagged eels released and estimated mortality of capture; estimated fishing mortality by year, extrapolated.

Year	Reported landings, t	Tags released	Estimated mortality, /a	Fishing mortality, extrapolated
2006	366	600	0.1	0.097
2007	418			0.111
2008	389	200	0.1	0.103
2009	310			0.082
2010	307			0.081
2011	271			0.072

3.4.3 East Coast stock indicators

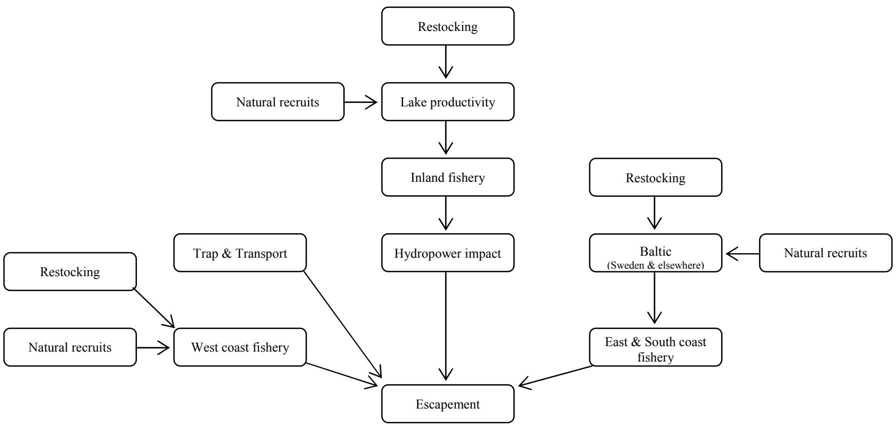
Average reported landings in 2006 and 2008 was 377 ton (0.4 million eels); fishing mortality in those years was estimated at F=0.10. Consequently, the stock of silver eels at large was in the order of $B_{2008} = \frac{C}{F} = \frac{377}{0.10} = 3770$ ton (4 million eels). The assessment of the trend in fishing mortality, above, assumes that this stock at large has not changed in recent years. Correspondingly, B_{best} is stable, B_{best} = 3770 ton over recent years. It should be noted that this estimate of B_{best} represents the potential escapement if the silver fishery on the Swedish East Coast would not exist –anthropogenic impacts in other areas (migration obstacles, yellow eel fishing, silver eel fishing, hydropower mortality; in inland and coastal habitats; in Sweden and all other Baltic countries) are not taken into account.

Current escapement is estimated as $B_{current}$ = B_{best} – catch. For 2011, $B_{current}$ = 3770 – 271 = 3499 ton (3.9 million eels). If the decline in landings is indeed caused by a diminishing fishing impact, $B_{current}$ will have increased since the implementation of the Eel Management Plan accordingly.

Without a comprehensive assessment of the whole Baltic eel stock, no estimate of B_0 can be provided. Dekker & Sjöberg (subm.) estimate that historical escapement (1950s – 1970s) has been in the order of 5 000 ton (≈10 million eels). $B_{historic}$, however, is a proxy for B_{lim} rather than B_0 (ICES 2007). In the absence of a better estimate, it is assumed here that $B_{historic}$ was 40% of B_0, and hence B_0 was $2.5 \times B_{historic}$ = 12 500 ton.

The fishery on the East Coast does not have delayed effects on future silver eel escapement. Future catches and impacts will be determined by future trends in the stock and fishery that cannot be foreseen yet. However, in deriving country wide stock indicators (chapter 4), delayed effects of other anthropogenic actions in other areas will need to be considered - notably the slow recovery of the stock on the West Coast following the recent closure of the fishery, and the delayed effects of current restocking in inland waters. To enable a country-wide medium-term projection, estimates of future stock indicators for the East Coast are required too. It has therefore been assumed that current conditions (2011) on the East Coast continue into the future without any change.

3.5 National stock indicators



In the previous sections, stock indicators have been derived for various parts of the national stock. In this section, all stock indicators are compiled, and national sums/averages derived.

In recent years, management restrictions have been applied to reduce anthropogenic impacts on the eel stock, resulting in declining anthropogenic impacts. In most cases, however, the expected recovery of the stock will take place over a range of years; mortality has indeed changed due to management measures, but the stock has only just begun to restore. Except for the inland restocking, only an over-simplified assessment of this recovery trajectory is presented.

Table 11 summarises anthropogenic mortalities by area, from the range of years reported in the Swedish Eel Management Plan until the last data year. A country-wide lifetime mortality rate is added, using the calculation procedure of Dekker (2010)[2]. The range of years covered in this table corresponds to the shortest range for each of the constituting parts - notably that for the East Coast fishery. In the next chapter, medium-term projections will be plotted. Most of these medium-term projections are based on an assumed continuation of the status quo concerning anthropogenic impacts. However, it is rather unlikely that the status quo is indeed continued without further change: both the stock and the anthropogenic impacts are likely to develop. Hence, the medium-term projections give an indication of delayed effects of current management measures, but otherwise will not adequately represent the future. For that reason, projections beyond 2012 have been omitted from Table 11.

Table 12 summarises the biomass indicators for the year 2011. For the East Coast, the indicators reflect the impact of the Swedish fishery only; impacts in other areas affecting the earlier life stages of these eels have not been included. The indicators in this table do take into account both naturally recruited eels and restockings, since there is no way to separate one from the other consistently. Restocked eels dominate in inland waters, but they make a marginal contribution to the country-wide Totals.

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[2] Delayed effects of a changing anthropogenic mortality regime are directly taken into account for ΣA, while $B_{current}$ shows the actual trend, in which delayed effects gradually come through (ICES 2011). The anthropogenic mortality averaged over the whole country is calculated using the relation between %SPR and ΣA [$\Sigma A=-\ln(\%SPR)$], the averaging procedure of Dekker (2010) [average %SPR is the B_{best}-weighted average of the %SPR's of the constituting parts], and finally back-converting the average %SPR to a mortality ΣA for the whole country.

Table 11 National stock indicators: temporal trend in total anthropogenic impact ΣA by area and year. For inland waters (and the country total), estimates are given for a low (left) or high (right) assumption on natural mortality M.

Year	West Coast	Trap & Transport	Inland waters M=0.05	Inland waters M=0.10	East Coast	Total M=0.05	Total M=0.10
2005	2.39		0.79	1.04			
2006	2.66		0.80	1.09	0.10	0.37	0.36
2007	1.91		0.84	1.10	0.11	0.36	0.35
2008	1.86	undefined	0.97	1.28	0.10	0.36	0.35
2009	1.19		1.05	1.38	0.08	0.30	0.29
2010	1.20		1.17	1.55	0.08	0.31	0.29
2011	0.93		1.25	1.58	0.07	0.29	0.26
2012	0		*1.32*	*1.64*	*0.07*	0.13	0.10

Table 12 National stock indicators for the year 2011. Note that in this table, indicators do not distinguish natural from restocked eels.

	West Coast	Trap & Transport	Inland waters M=0.05	Inland waters M=0.10	East Coast	Total M=0.05	Total M=0.10	units
Catch/kill	84	-	411	223	271	766	578	ton
Catch/kill	0.5	-	0.70	0.38	0.29	1.49	1.17	million
$B_{current}$	12	7	165	58	3 499	3 683	3 576	ton
$N_{current}$	0.02	0.007	0.22	0.08	3.71	3.97	3.83	million
B_{best}	1 154	0	576	280	3 770	5 500	5 204	ton
N_{best}	1.7	0	0.92	0.46	4.0	6.62	6.16	million
B_0	1 154 – 11 540	0	1076	580	12 500 §	14 730	14 234	ton
N_0	1.7-17	0	0.80	0.49	25.00	16.25	15.94	million
ΣA	0.93	undefined	1.25	1.58	0.075 †	0.29	0.26	rate
%SPR	40%	undefined	29%	21%	93% †	75%	77%	%
%SSB	1 - 0.1%	-	15%	10%	28%	25%	25%	ton/ton, %
%SSB	2 - 0.2%		28%	16%	27%	24%	24%	# / #, %

† Partial estimate; covers the Swedish silver eel fishery only.
§ B_{best} in 1950-1970 is estimated at ≈5 000 ton. It is assumed that historical B_{best} = 40% of B_0.

4 Stock status and management targets

4.1 Management targets in the Swedish Eel Management Plan

The Swedish Eel Management Plan subscribes to the objectives of the European Eel Regulation and emphasises a rapid increase of silver eel escapement, to a level at which the stock decline is expected to stop and turn into an increase. To this end, a “Balance Equation” was developed, in which the anthropogenic impacts that are allowable under a sustainable management regime are compared to the actual impacts. In this Balance Equation, all quantities are expressed in numbers of silver eels; where anthropogenic impacts affect other life stages, an ad-hoc conversion is given. The allowable impact is tentatively calculated as a percentage (20% for yellow eel dominated areas and 10% for silver eel dominated areas) of the potential production from the current stock; that combines the concepts of A_{lim} (limit mortality) and B_{best} (the potential production from the current stock). Since the current potential production B_{best} depends on past recruitment and restocking, this Balance Equation is time-dependent. Moreover, the yellow-eel-conversion-factor *k* is affected by the intensity of the fishery, and hence by past and future fishing restrictions. As a consequence, the application of this Balance Equation and the extrapolation to other years is cumbersome.

Table 13 lists the Balance Equation in its original form in line 1. After submission of the Eel Management Plan, it was realised that “Old restocking, U” is also included in “Silver eel production from fresh water, S” (S=Sötvatten, fresh water), resulting in double-counting the same eels. Line 2 therefore copies the Balance Equation, omitting “Old restocking, U”. The third line uses the estimates as specified in the Swedish Eel Management Plan, while the fourth line applies the correction for “Old restocking”. Note that the Eel Management Plan presents the equation in an unbalanced form, concluding that “an additional 550 000 silver eels must survive”; that quantity has been added in Table 13 under the label “extra”.

Line 6 and 7 present the equation for the year 2011. The figures presented differ from the EMP for two reasons: first, data represent the status as in 2011 rather than 2006, and secondly, all quantities are derived from the revised assessments presented in chapter 3 above. Line 7 indicates that the 2011 impacts exceeded the target set in the Eel Management Plan. The closure of the West Coast fishery as of spring 2012, however, fills the gap almost exactly (line 8 & 9).

For other anthropogenic impacts (pollution, spread of parasites, disruption of migration by transport, etc), no targets have been set in the Swedish Eel Management Plan, and no quantitative assessment is currently achievable.

Table 13 The "Balance Equation" of the Swedish Eel Management Plan. Along the top, the terms are explained. From top to bottom: the definition of the equation (with a later correction), the evaluation in the Eel Management Plan EMP, and the new evaluation for the years 2011 and 2012. All quantities are given here in millions of silver eel (equivalents).

	Yellow eel dominated areas	Silver eel dominated areas		West Coast fishery	East Coast fishery	Inland fishery	Hydropower mortality	2007 restrictions	Old restocking	Increased turbine survival	New restocking	Required measures	Line number
	Allowable impacts		≥	Actual impacts									
EMP	$0.2*V$	$+ 0.1*(O+S)$	≥	$k*F_V$	$+ F_O$	$+ F_S$	$+D$	$– F_{07}$	$– U$	$– T$	$– H$	– extra	1
corr.	$0.2*V$	$+ 0.1*(O+S)$	≥	$k*F_V$	$+ F_O$	$+ F_S$	$+D$	$– F_{07}$	---	$– T$	$– H$	– extra	2
EMP	0.2*1.000	+ 0.1*(1.570+0.300)	≥	0.5*1.821	+ 0.576	+ 0.083	+ 0.280	– 0.390	-0.210	– 0.140	– 0.185	– 0.550	3
corr.	0.2*1.000	+ 0.1*(1.570+0.300)	≥	0.5*1.821	+ 0.576	+ 0.083	+ 0.280	– 0.390	---	– 0.140	– 0.185	– 0.760	4
	0.387		≥	0.375									5
2011	0.2*1.700	+0.1*(4.000+0.373)	≥	0.5*1.200	+0.400	+0.135	+0.250			- 0.007			6
2011	0.777		≥	1.378									7
2012	0.2*1.700	+0.1*(4.000+0.373)	≥	0	+0.400	+0.135	+0.250			- 0.007			8
2012	0.777		≥	0.778									9

4.2 Management targets in the EU Regulation & the ICES/WGEEL framework for assessment

The EU Eel Regulation sets a long term general objective ("the protection and sustainable use of the stock of European eel"), delegating the local management, the implementation of protective measures, the monitoring, and the local post evaluation to its Member States (EU 2007; Dekker, 2009). A target is set for the biomass of silver eel escaping from each management area: at least 40 % of the silver eel biomass relative to the escapement if no anthropogenic influences would have impacted the stock and recruitment might not have declined. Since current recruitment is far below pre-1980 levels and is assumed to be so due to anthropogenic impacts, return to this target level is not expected before decades or centuries even if all anthropogenic impacts are removed (Åström & Dekker 2007). In the current situation of low stock abundance and declining recruitment, the stock is below the biomass level aimed for, and – despite management actions taken – may not even have started to recover. In this situation, biomass targets and biomass assessments are not very informative (Dekker 2010).

However, a system of parallel mortality targets has been developed (Dekker 2010; ICES 2010, 2011, 2012). The template for the 2012 post-evaluation supplied by the EU Commission includes a request to report on the quantities $B_{current}$, B_{best}, B_0 and ΣA – enabling the application of this mortality framework. A lifetime mortality of $\Sigma A=0.92$ can be shown to match the 40% biomass target. At very low biomass, however, ICES (2009) reduces the anthropogenic mortality advised, to reinforce the tendency for stocks to rebuild. ICES applies a reduction in mortality reference values that is proportional to the biomass (i.e. a linear relation between the mortality rate advised and biomass, showing up as a curved line on logarithmic scale). This results in a Precautionary Diagram, as modified by ICES (2012). This diagram is applied below (Figure 13, Figure 14).

For other anthropogenic impacts (pollution, spread of parasites, disruption of migration by transport, etc), no targets have been set in the national Eel Management Plan or the European Regulation, and no quantitative assessment is currently achievable.

The first diagram (Figure 13) shows the status of the stock, as in 2011; the bubbles are scaled in accordance with the abundance of the stock (B_{best}) in each of the areas. The second diagram (Figure 14) shows the recent trend in stock indicators; for readability, the bubbles have been left out here. Additionally, the second diagram shows the delayed effect current management actions will have in the coming years – a medium-term projection (dotted lines). In both diagrams, two inland estimates are given, for M=0.05 and M=0.10 respectively, reflecting a low and a high assumed natural mortality level. For the country-wide Total, only one estimate is given (for M=0.10, the conservative estimate resulting in a higher level of precaution). Due to the relatively small contribution of the inland stock to the total stock, the inland stock has a minor influence on the country total. The country-wide Total estimate based on M=0.05 would almost completely overlap with the one given.

In 2000, the impact of the West Coast fishery exceeded sustainable limits considerably. Fishing restrictions have since reduced the impact to approximately ΣA=0.93 in 2011, almost exactly the ultimate value of A_{lim}=0.92, had the silver eel escapement not been below the targeted 40% level. The closure as of spring 2012 brings the fishing impact down to zero (the downward dashed line); a recovery of the stock is expected in the coming years (horizontal dashed line). The West Coast stock contributes to the country-wide total for about 10%; the indicator for the country-wide Total in Figure 14 is projected to follow a parallel trajectory (immediate downward, followed by a recovery in the coming years), but at a smaller scale.

The inland stock is dominated by restocked eel, and the shift in the spatial distribution of the restocking has had a major impact on the status of the inland stock. From the year 2000 until the mid-2000s, the anthropogenic impacts on the inland stock declined, but returned to higher values since. Overall, the anthropogenic impacts on the inland stock have been above sustainable limits in all years. The most recent shift in spatial distribution of the restocking seems to deteriorate this situation. The current Trap & Transport programme is far too small to reverse this trend.

The East Coast fishery has a low impact (7%), on a large part of the total Swedish stock (ca. 70% of the total), and a moderate contribution to the total catch. Recent fishing restrictions have reduced the impact from 10% to 7%. The impact is estimated to be well within sustainable limits, but it should be stressed that this covers only the Swedish part of the lifetime anthropogenic impacts.

The trend in stock indicators for the country-wide Total has largely followed the East Coast trend up to 2011 (the East Coast being the bigger part of the total stock), but the total closure of the West Coast fishery is expected to take over in the coming years (the bigger change).

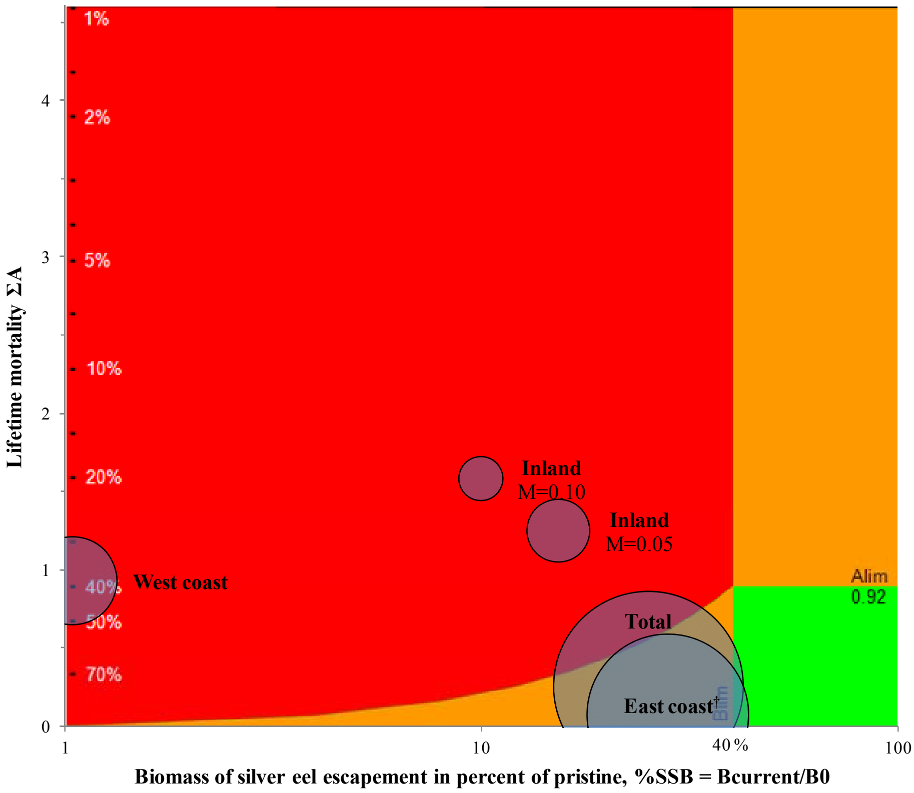


Figure 13 Precautionary Diagram for the Swedish eel stock, as in 2011. The size of each bubble is proportional to B_{best}, indicating what part of the stock is found in each area. The location of each bubble quantifies the status of the stock (horizontal, in percentage of the notional pristine stage) and the magnitude of anthropogenic impacts on the eels in each area (vertical). The vertical axis is expressed as mortality rate (outside) and corresponding survival (inside the axis) relative to the un-impacted state. For the inland area, two separate estimates are given, assuming a low (M=0.05) respectively a high (M=0.10) value for natural mortality.

† For the East Coast, only the impact of the Swedish silver eel fishery is included; impacts on other life stages, in other areas/countries are not.

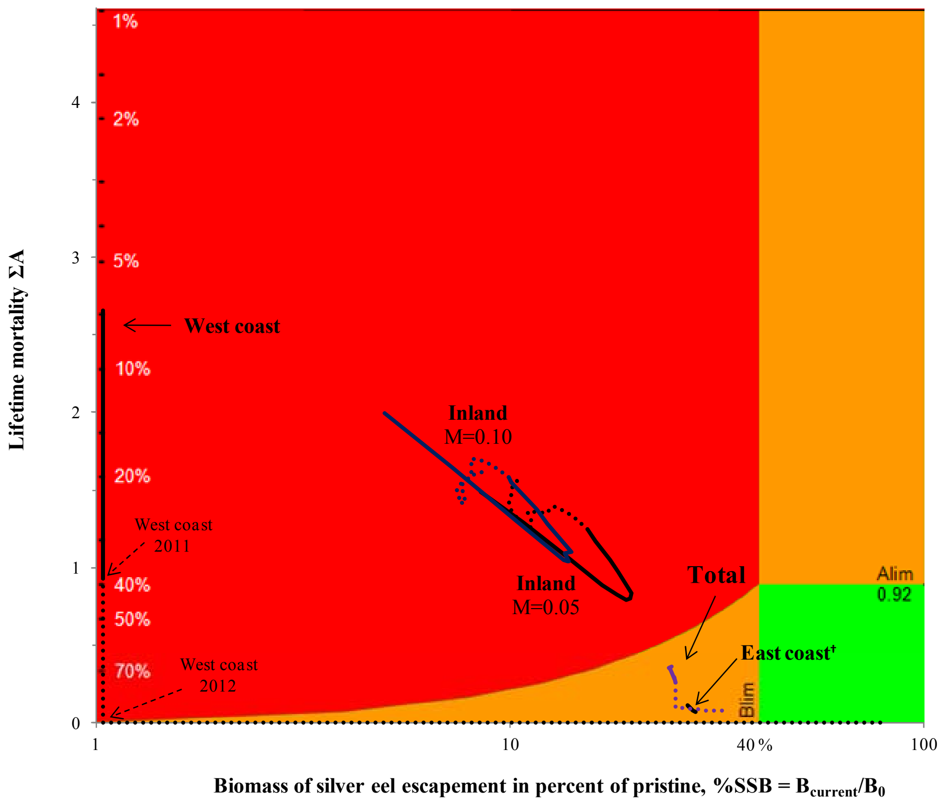


Figure 14 Precautionary Diagram for the Swedish eel stock: trend in status and anthropogenic impacts from 2000 until 2011 (drawn lines) and predicted trend in the coming years, under a status quo assumption (dotted lines). See Figure 13 for further explanation.

† For the East Coast, only the impact of the Swedish silver eel fishery is included; impacts on other life stages, in other areas/countries are not.

References

Anonymous 2007 Council Regulation (EC) No 1100/2007 of 18 September 2007 establishing measures for the recovery of the stock of European eel. Official Journal of the European Union L 248/17.
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:248:0017:0023:EN:PDF (English)
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:248:0017:0023:SV:PDF (Swedish)

Anonymous 2008 Förvaltningsplan för ål. Bilaga till regeringsbeslut 2008-12-11 Nr 21 2008-12-09 Jo2008/3901 Jordbruksdepartementet. 62 pp. [Swedish eel management plan. In Swedish]
https://www.fiskeriverket.se/download/18.7c5197de123343f05d280007183/%C3%85l_f%C3%B6rvaltningsplan_bilagor_beslut_20081211.pdf (Swedish)
http://www.fishsec.org/downloads/1233757502_69937.pdf (English)

Ăström M. and Dekker W. 2007 When will the eel recover? A full life-cycle model. ICES Journal of Marine Science, 64: 1–8.

Clevestam P. D. & Wickström H. 2008 Rädda ålen och ålfisket! – Ett nationellt bidrag till en europeisk förvaltningsplan. Vetenskaplig slutrapport från pilotprojekt till Fonden för fiskets utveckling. Swedish Board of Fisheries. Dnr: 231-1156-1104 (in Swedish).

Dekker W. 2000 A Procrustean assessment of the European eel stock. ICES Journal of Marine Science 57: 938-947.

Dekker W. 2004 Slipping through our hands - Population dynamics of the European eel. PhD thesis, 11 October 2004, University of Amsterdam, 186 pp.
http://www.diadfish.org/doc/these_2004/dekker_thesis_eel.pdf

Dekker W, 2008 Coming to Grips with the Eel Stock Slip-Sliding Away. *In* International Governance of Fisheries Eco-systems: Learning from the Past, Finding Solutions for the Future. *Edited by* M.G. Schlechter, N.J. Leonard and W.W. Taylor. American Fisheries Society, Symposium **58**, Bethesda, Maryland. pp 335-355.

Dekker W. 2009 A conceptual management framework for the restoration of the declining European eel stock. Pages 3-19 in J.M. Casselman & D.K. Cairns, editors. Eels at the Edge: science, status, and conservation concerns. American Fisheries Society, Symposium 58, Bethesda, Maryland.

Dekker W. 2010 Post evaluation of eel stock management: a methodology under construction. IMARES report C056/10, 67 pp.

Dekker W., Deerenberg C. & Jansen H. 2008 Duurzaam beheer van de aal in Nederland: Onderbouwing van een beheersplan. IMARES rapport C041/08, 99 pp.

Dekker W., Wickström H. & Andersson J. 2011a Status of the eel stock in Sweden in 2011. Aqua reports 2011:2. Swedish University of Agricultural Sciences, Drottningholm. 66+10 pp.

Dekker W., Wickström H. & Andersson J. 2011b Ålbeståndets status i Sverige 2011. Aqua reports 2011:1. Sveriges lantbruksuniversitet, Drottningholm. 70+10 pp.

ICES 2007 Report of the 2007 session of the Joint EIFAC/ICES Working Group on Eels. Bordeaux, 02-07 September 2007. EIFAC Occasional Paper. No. 39, ICES CM 2007/ACFM:23. Bordeaux/Copenhagen, ICES. 2007. 526p.

ICES 2009 Report of the ICES Advisory Committee, 2009. ICES Advice, 2009. Books 1 - 11. 1,420 pp.

ICES 2010 Report of the Study Group on International Post-Evaluation on Eels (SGIPEE), 10–12 May 2010, Vincennes, France. ICES CM 2010/SSGEF:20. 42 pp.

ICES 2011 Report of the Study Group on International Post-Evaluation on Eels. (SGIPEE), 24–27 May 2011, London, UK. ICES CM 2011/SSGEF:13. 39 pp.

ICES 2012 Report of the 2011 session of the Joint EIFAC/ICES Working Group on Eels. Lisbon, Portugal, from 5 to 9 September 2011. ICES CM 2011/ACOM:18. Rome, FAO/Copenhagen, ICES. 2012. 841p.

Lagenfelt, I. *in prep.* 2012 Ål vandring i Göta älv, Telemetristudier på blankålsvandring 2010-2011, Länsstyrelsen i Västra Götalands län, Vattenvårdsenheten Rapport 2012 manuskript.

Schmidt J. 1906 Contributions to the life-history of the eel (Anguilla vulgaris, Flem.). Rapp P.-V. Reun. Cons. perm. int. Explor. Mer 5, 137–264.

Ăström M. and Dekker W. 2007 When will the eel recover? A full life-cycle model. ICES Journal of Marine Science, 64: 1–8.

Appendix 1 - Productivity of inland waters.

Introduction

The Swedish Eel Management Plan estimates biological production of eel in inland waters on the basis of surface areas of habitats and the relation between known productivity (local fishing yield) and temperature, nutrients and distance to the sea/Skagerrak; potential effects of restocking have not been included. Production has been estimated for 32 500 individual lakes; the total productivity is estimated at nearly 350 ton.

Analysis of silver eels from inland lakes and from the outlet of the Baltic, however, indicates that a large part of the stock consists of eels of restocked origin (Clevestam and Wickström 2008). More than 90% of inland catches consists of restocked eel (*ibid*.). The assessment in the Eel Management Plan, though, ignores the influence of restocking on lake productivity, while the yield data being analysed do contain eels derived from restocking. In this appendix, we explore what contribution restocking might have made to the total yield, and how that alters the extrapolation to lakes for which no catch data are available.

Material

For this analysis, the data set used in 2008 was copied, containing information on > 32 500 lakes concerning surface area, distance to the coast resp. to the Skagerrak, phosphate concentration (which itself was based on a statistical prediction) and temperature (number of days with temperature > 5 °C). For 27 lakes, information on fishing yield for individual lakes is available (Figure 15). Information on restocking was selected from the database of (historical and present) restockings, selecting the years that could reasonably have contributed to the reported fishing yield, i.e. year of restocking, mean age and the year for which fishing yield was reported were matched. For those lakes for which no fishing yield is reported, information on restocking was selected for the range of years that occurred most often amongst the 27 known lakes, i.e. generating a yield in 2000-2006. The data for the 27 lakes of known yield are reproduced in Table 15. Data for the remaining 32 500 lakes and 50 restocking locations were linked, matching name and position. Less than 10% of the restocking positions were not represented in the database of lakes, most often since restocking took place into running waters and/or positions were only approximately specified.

Figure 16 presents the relation between variables for the 27 lakes of known yield. These figures show that highest yield is found in lakes that are closest to the coast (with one exception, Lake Ymsen), that have a phosphate concentration above 0.05 mg/L, that have 200 days or more per year with a temperature above 5 °C (Bondsjön with 170 days is somewhat exceptional), and that have been restocked with more than 10 eels per hectare (Sövdesjön and Råbelövsjön, restocked with 47 and 43 eels/ha, show a production below 1 kg/ha).

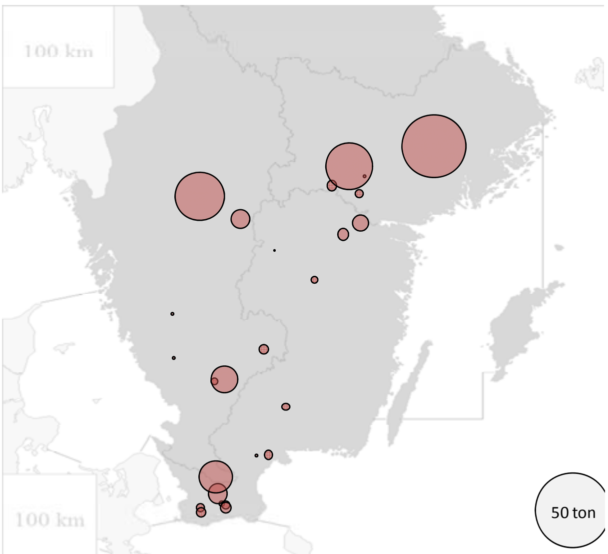


Figure 15 Fishing yield for 27 individual lakes. The assessment of the inland productivity is based on the assumption that these data represent the total production from these lakes.

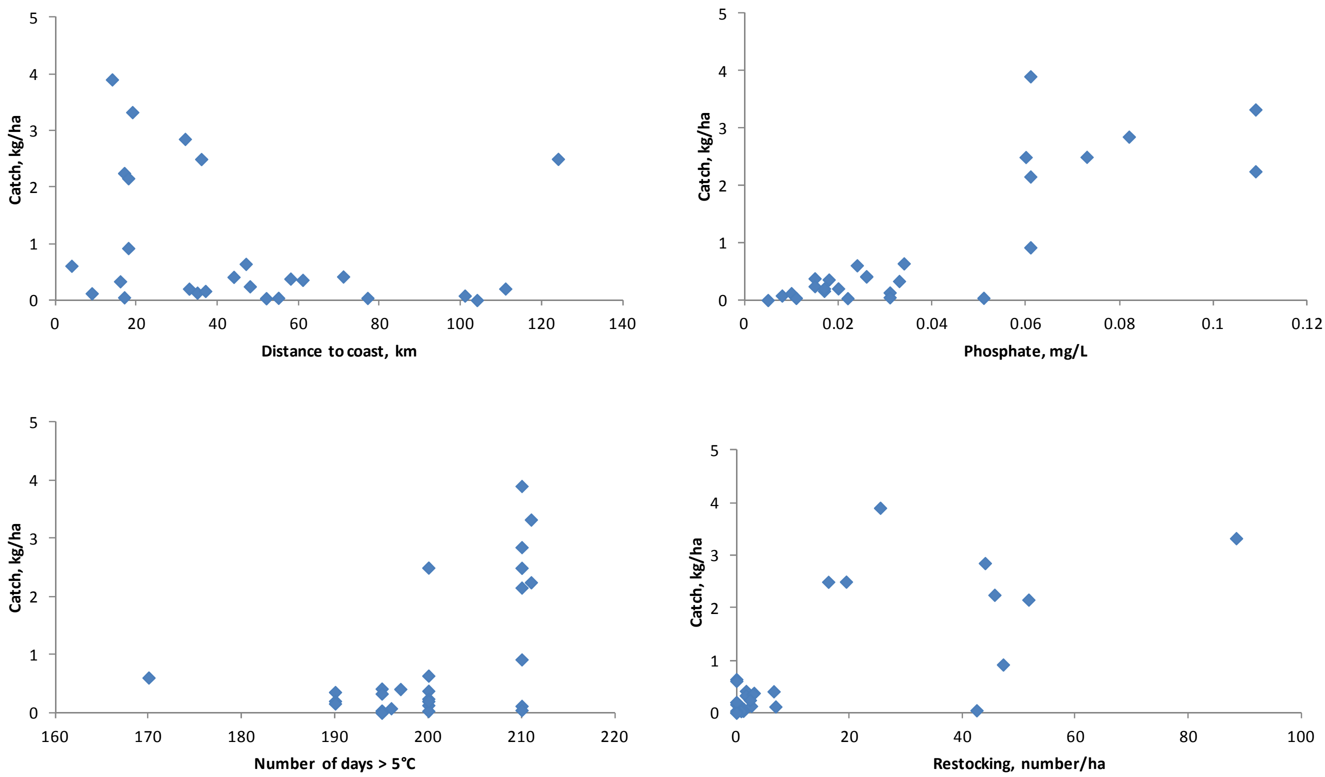


Figure 16 Relation between catch per hectare (vertical) and various explanatory variables for the 27 lakes with known fishing yield. Note that each of the sub-plots shows the raw data, but inter-relationships between the explanatory variables are not taken into account.

Analysis

The Swedish Eel Management Plan fits a model on data concerning known yield, surface area, phosphate concentration, distance to the Skagerrak and temperature. Preliminary attempts to extend this model to include restocking, however, failed completely: models failed to fit, showed contradictory relations, over-fitted the data, etc. Either the models are fundamentally wrong, or there is not enough information in the data to fit a more complex model.

To explore the information content of the data, an analysis was made of the data set of all >32 500 lakes, applying Principal Component Analysis and Cluster Analysis. Variables included were: latitude, distance-to-the-coast, surface area, temperature (#days > 5 °C), phosphate concentration, restocking (numbers per hectare) and an indicator whether yield data were available or not; 7 variables in total. A Principal Component Analysis quantifies the dimensionality of the data – that is: it quantifies to what extent the explanatory variables are correlated to each other – to what extent a smaller number of explanatory variables would have given the same information. Cluster Analysis is used to find out in what groups the variables fall apart; tight groups of variables might indicate that one or more of the variables included do not actually contribute much information. The cluster diagram (Figure 17) indicates that the 7 variables fall apart into two groups: those variables characterising spatial trends (latitude, temperature, distance to the coast and phosphate) versus those characterising the individual lake (surface area, restocking density and has-or-not catch statistics). Except for the strong relation between temperature and latitude, correlations are rather weak: clusters are formed at relatively high distance.

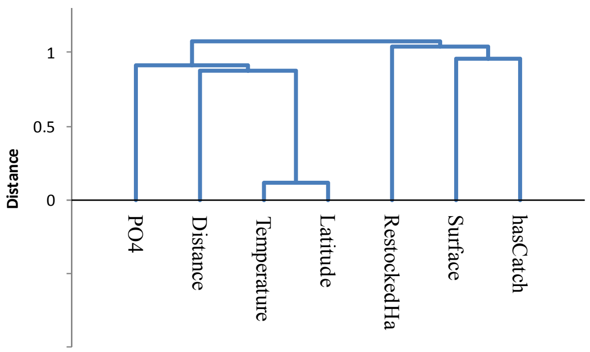


Figure 17 Cluster Analysis of lake characteristics.

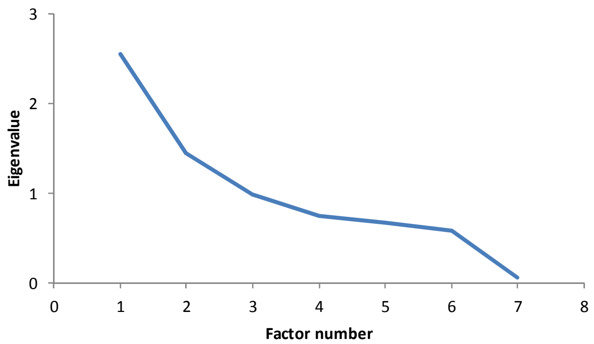


Figure 18 Principal Component Analysis, Scree-plot of 7 lake characteristics.

The Scree-plot (Figure 18) produced by the Principle Component Analysis explains why the production model adding restocking fits so poorly: only the first two or three factors have an Eigenvalue above 1. That is: the dataset of > 32 500 lakes is essentially characterised by two or three different characteristics; additional variables repeat the information already contained in the first two or three. Fitting more than two or three explanatory variables will not improve any model. And hence, the three-variable model of the Swedish Eel Management Plan cannot be improved by adding a fourth variable. Apparently (and not surprisingly), restocking is focused on lakes that have high production characteristics: a high temperature and phosphate content, which happens to be found in lakes close to the coast. And thus, restocking, temperature, phosphate and coastal distance are closely correlated amongst themselves. The low variation in lake characteristics does not allow fitting a more complex model; the data do not allow discriminating between the 2009 model and an alternative based on restocking data.

Given this situation, four different models were applied:

1. A replication of the model in the Swedish Eel Management Plan (ÅFP model)
2. A standardised version of the above using the same explanatory variables, adopting statistical methodology as in the subsequent models (Generalised Linear Model, explained variable is Catch, log-link, Poisson-error, offset=log of lake surface, explanatory variables comprise latitude, distance to the coast, temperature and phosphate)
3. A model taking the restocked quantities as the starting point, ignoring natural recruitment and allowing for effects of temperature and phosphate on growth and survival (Generalised Linear Model, explained variable is Catch, log-link, Poisson-error, offset=log of restocked numbers, explanatory variables comprise temperature and phosphate),
4. A most simplified model, only taking restocking into account (Generalised Linear Model, explained variable is Catch, log-link, Poisson-error, offset=log of restocking numbers, no explanatory variables other than a general intercept).

Models and model parameters are specified in Table 14. Because the data contain no information to discriminate between the models, no model fitting information is supplied. For all models, the fit to the data is doubtful. This questionable fit is a characteristic of the low information contained in the data, not a characteristic of the models themselves.

Table 14 Model formulae and parameters fitted.

Model	Formula & fitted parameters
1 ÅFP model	$Catch/Surface = 10^{1.76 \times log_{10}(Phosphate) - 0.77 \times log_{10}(Distance2Skagerrak) + 6.03 \times log_{10}(Days > 5°C)}$
2 Natural recruits & productivity	$Catch = exp^{-93.9 + 0.172 \times Latitude + 0.0049 \times Distance2coast + 16.6 \times log(Days > 5°C) + 1.45 \times log(Phosphate) + log(Surface)}$
3 Restockings & productivity	$Catch = exp^{62.0 - 11.9 \times log_{10}(Days > 5°C) + 0.438 \times log(Phosphate) + log(Restocked)}$
4 Restocking only	$Catch = exp^{-2.52 + log(Restocked)}$

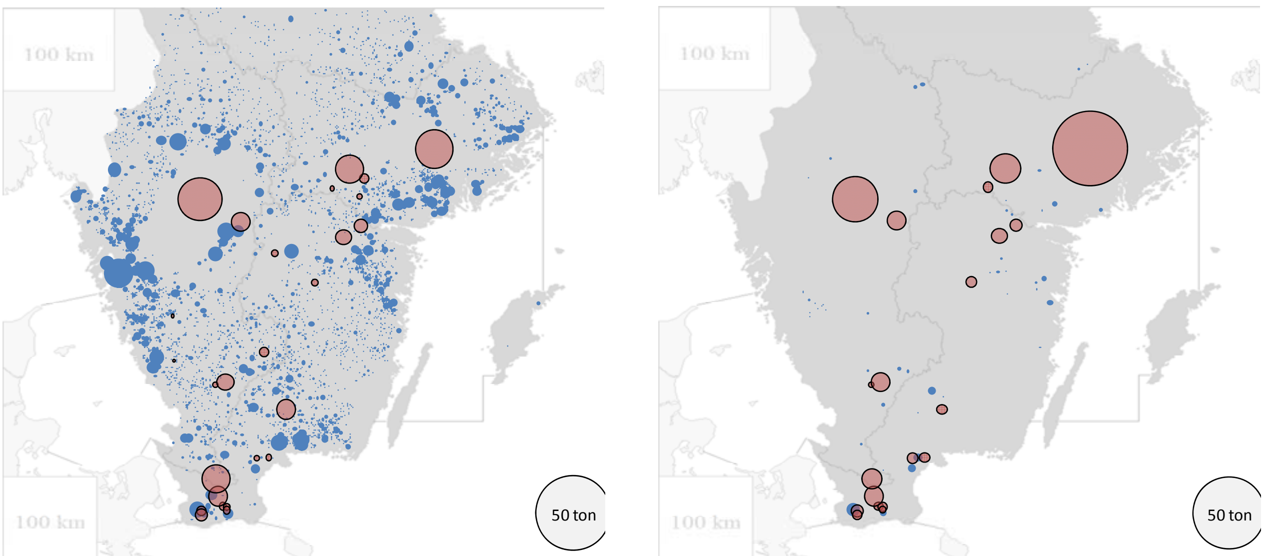


Figure 19 Comparison of model predictions focused on natural recruitment (left) or restocked eels (right). The plot shows the predicted yield per lake, for the lakes for which yield data are available (red) or not (blue). For both, these maps show the predicted yield, not the observed. Figure 15 (above) shows the original observations.

Results and Discussion

For each of the models, the observations and statistical predictions for the 27 observed lakes are listed in Table 15. Figure 19 compares the extrapolations from models 2 and 3 for all > 32 500 lakes (models 1 and 4 do not differ visibly from these). Both models give a reasonable prediction for the observed catch, except that the ÅFP model underestimates the yield from Lake Mälaren (the north-eastern big red bubble) substantially. The difference between the two models is in the extrapolation to all lakes for which no yield information is available. According to the ÅFP model, productivity in the 32 500 unobserved lakes is substantial, summing up to 284 ton. A yield of 68 ton is attributed to the 27 lakes, which are known to have yielded 110 ton. Using information on restocked quantities, however, a total production of 119 ton is predicted, of which 111 ton is attributed to the 27 lakes that actually yielded 110 ton. Apart from the difference in reproducing the observations, the main difference between the models is in the yield predicted for the >32 500 lakes for which no yield data are available. Their production is estimated at 284 ton respectively 8 ton. The low information content of the data does not allow making a formal test on this huge difference.

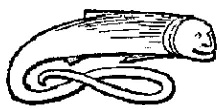
According to the analysis based on restocking, a total of 1.4 million restocked eels resulted in a total of 111 ton fishing yield. That conforms to an average productivity of 80 grams per stocked eel. Assuming an average survival from glass eel to marketable size of 10% (15 years of 13% mortality, M=0.138), that is 800 gram per eel in the catch – in reasonable agreement with the observed average weight of 943 ± 410 gr (Clevestam & Wickström 2008).

According to the analysis in the Swedish Eel Management Plan, approximately 284 ton potential fishing yield was not represented in the set of 27 lakes with known yield. Assuming the same 800 gram per individual and 10% survival to marketable size, this 284 ton is derived from 3.6 millions of recruits, the vast majority (93%) of which is not represented in the restocking database. In recent years, the quantities of natural recruits monitored (see section 2.1) averaged 380 kg per year; at an average weight of 25 gr per individual, this would number some 15 000 naturally recruiting eels, though this includes only the 8 rivers being monitored. That is: the 3.6 million natural recruits have not been observed in the field. Either our monitoring covers only a tiny fraction of the actual natural recruitment, or the 3.6 million is a number far too high. However, the potential presence of 3.6 million natural recruits per year in our rivers should definitely create an opportunity to monitor their presence in the standing stock. Electro-fishing data are available, but these have not yet been analysed with respect to the eel.

The analysis in the Swedish Eel Management Plan, as well as the above re-analysis of the same data, considers the relation between known fishing yield and explanatory variables. Implicitly, it is assumed that fishing yield gives an adequate picture of total production, that escapement of silver eel is a negligible quantity. This seems an unlikely assumption, but the currently available information hardly allows a critical re-assessment. For both analyses, the actual production must have been above the reported fishing yield, and hence, the actual numbers of recruits must have been above the calculated numbers (more than 1.4 million respectively more than 3.6 million). In the next Appendix (Appendix 2), an assessment of the impact of fisheries and hydropower generation on the silver eel run is given, using the restocking data as the starting point. It is shown there, that the historical records of commercial fishing on the great lakes Mälaren, Vänern and Hjälmaren does set a lower bound to the inland stock productivity.

Table 15 Data on inland productivity for the 27 lakes for which information on fishing yield is available. In addition to this, predicted production is given for four different analysis models. (To protect the privacy of individual fishers, most lake names are anonymous. Table 16 uses identical codes).

Lake Anonymous code or name	**Latitude**	**Surface ha**	**Distance to coast km**	**Distance to Skagerrak km**	**Phosphate mg/L**	**#days>5°C**	**Restocked # per annum**	**Observed catch, kg**	***Prediction, AFP2008, kg***	***Prediction, natural recruits & survival, kg***	***Prediction, restockings & survival, kg***	***Prediction, restockings only, kg***
Lake a	56.631	14 753	52	983	0.022	200	11 770	473	*3 272*	*3 671*	*866*	*943*
Lake c	56.927	17 319	58	664	0.015	200	53 630	6 556	*2 644*	*2 689*	*3 336*	*4 297*
Bondsjön	62.636	33	4	2 725	0.024	170	0	20	*4*	*1*	*0*	*0*
Lake d	55.485	277	17	711	0.109	211	12 654	622	*1 352*	*1 187*	*993*	*1 014*
Lake e	55.533	264	14	740	0.061	210	6 719	1 030	*449*	*448*	*433*	*538*
Lake f	55.528	173	19	716	0.109	211	15 303	575	*838*	*750*	*1 201*	*1 226*
Lake g	58.623	7 390	16	2 192	0.033	195	12 321	2 450	*1 787*	*2 574*	*1 462*	*987*
Hjälmaren	59.239	47 691	71	2 513	0.026	195	81 243	19 843	*6 817*	*17 052*	*8 684*	*6 509*
Lake h	56.107	5 017	9	903	0.010	210	34 737	600	*302*	*665*	*1 014*	*2 783*
Mälaren	59.454	87 200	44	2 366	0.026	197	575 636	35 656	*13 112*	*33 774*	*54 317*	*46 119*
Lake j	59.135	1 791	55	2 552	0.051	195	0	68	*830*	*1 549*	*0*	*0*
Lake l	56.100	630	17	916	0.031	210	26 786	30	*275*	*448*	*1 283*	*2 146*
Lake l	55.869	3 918	36	669	0.060	210	63 715	9 770	*6 989*	*7 631*	*4 074*	*5 105*
Lake n	58.503	9 500	35	2 224	0.031	200	24 892	1 245	*2 055*	*4 949*	*2 128*	*1 994*
Lake o	57.256	3 396	111	746	0.020	190	0	688	*772*	*467*	*0*	*0*
Lake p	55.566	247	18	735	0.061	210	12 770	532	*421*	*428*	*822*	*1 023*
Lake q	58.007	13 035	77	2 329	0.011	195	15 866	477	*434*	*1 114*	*1 164*	*1 271*
Lake r	59.033	2 780	61	2 266	0.018	190	8 048	993	*223*	*349*	*997*	*645*
Lake s	55.577	272	18	729	0.061	210	12 839	250	*468*	*474*	*827*	*1 029*
Lake t	57.640	147	47	554	0.034	200	0	94	*109*	*80*	*0*	*0*
Tisnaren	58.947	3 785	37	2 234	0.017	190	0	605	*277*	*383*	*0*	*0*
Tjärnesjön	57.153	318	33	575	0.017	200	0	64	*68*	*54*	*0*	*0*
Lake u	56.898	1 686	48	693	0.015	200	4 059	408	*249*	*248*	*253*	*325*
Vänern	58.910	269 100	101	506	0.008	196	332 133	21 073	*16 581*	*20 749*	*19 946*	*26 610*
Vättern	58.330	56 600	104	2 285	0.005	195	0	20	*476*	*1 865*	*0*	*0*
Lake v	55.684	1 197	32	711	0.082	210	52 675	3 411	*3 532*	*3 480*	*3 862*	*4 220*
Lake w	58.670	1 310	124	656	0.073	200	25 430	3 271	*3 289*	*3 745*	*3 162*	*2 037*
Sum 27 lakes		549 830					1 383 226	110 823	*67 624*	*110 823*	*110 823*	*110 823*
Sum >32 500 lakes		3 292 104					1 488 778	116 000	*352 724*	*370 869*	*118 541*	*119 280*



Appendix 2 - The impact of fishing and hydropower generation on silver eel runs

Introduction

The Swedish Eel Management Plan estimates the impact of hydropower generation on the silver eel run, using information on the productivity of inland waters (that is: historical fishing yield - see Appendix 1), an average impact per hydropower station and the known location and number of hydropower stations. Appendix 1 (above) discusses the relation between natural lake productivity, the contribution from restocking and fishing yield - concluding that it is most likely that restockings are dominating the inland production. This Appendix makes a revised assessment, estimating the impact of hydropower generation on the revised production estimates. In addition to this, the assessment in the Eel Management Plan assumed that the hydropower impact is affecting the whole inland production. In practice, however, it only affects the silver eels escaping the inland fisheries; there are no fisheries downstream of hydropower generation plants. In this Appendix, these impacts will be treated sequentially.

All in all, the assessment in this Appendix deviates from that in the Eel Management Plan in three aspects:

- Silver eel production is estimated on the basis of actual numbers restocked, rather than habitat carrying capacity;
- The sequential effect of both fishery and hydropower generation is taken into account;
- The temporal shift in the spatial distribution of restocking (Figure 12) is taken into account.

This results in a spatially and temporally structured assessment. Though both the spatial and the temporal patterns are based on observations, it is unlikely that estimates are reliable down to the level of individual lakes in individual years. Hence, only a limited amount of detail will be presented here.

Restocking, fishing yield and natural mortality

In this section, estimates of silver eel production will be derived from historical restocking records.

In the 1960s, mean annual catch in the lakes Mälaren, Vänern and Hjälmaren was respectively 2, 11 and 2 ton. In the mid 1950s, substantial restocking began in all three lakes, and in the years after, catches increased considerably – eventually to 40, 21 and 19 ton in the 1990s/2000s. More than 90% of that catch consists of eel derived from restocking (Clevestam and Wickström 2008). Apparently, restocked eels dominate the eel stock in these lakes, and current yield is derived from (past) restocking. These data enable an assessment of the relation between quantities restocked and resulting yield – that is: the survival of restocked eels up to the silver eel stage being exploited.

To calculate the production of silver eels from a given quantity of restocked eels, the following relations are applied:

$$meanLength_{silver} = 2.5 \times Latitude - 70$$

where $meanLength_{silver}$ is the mean length at silvering and latitude is measured in degrees. This relation between silvering length and latitude is a simplification of the actually observed spatial pattern; see Dekker et al (2011), Figure 14.

$$Growth = {}^{(Latitude - 37.5)}/_{5}$$

and growth is assumed to be constant over length and age, i.e. a linear relation between age and length.

$$meanAgeSilver = {}^{(meanLengthSilver - 7)}/_{Growth}$$

where the length of the glass eel (equivalent) is taken as 7 cm.

$$N_{silver,Age_{silver}} = Restocking \times exp^{-M \times Age_{silver}} \times fraction_{age_{silver}}$$

where Age_{silver} runs from (meanAgeSilver-10) to (meanAgeSilver+10), and

Fraction$_{silver}$ is the fraction of the catch by age group, as observed in the 2003 catch sampling; fractions are specified per age class, taking age relative to the observed mean age (Figure 20).

Restocking is the number of glass eel equivalents, as observed (Section 2.2.2),

M is the natural mortality, expressed as an instantaneous mortality rate.

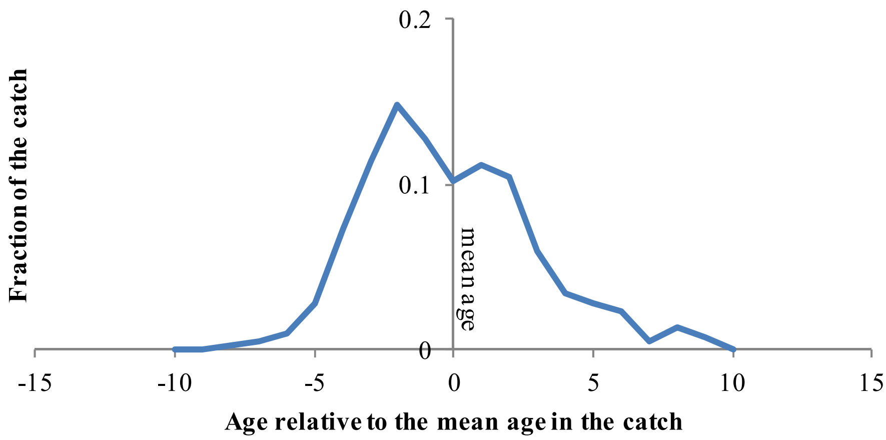


Figure 20 Relative composition of the catches in inland waters, by age, where age is expressed relative to the observed mean age. Data from the 2003 catch sampling programme.

The value of M, the natural mortality rate, is unknown. A value of M=0.1385 is frequently applied, giving Dekker (2000) as a reference – but Dekker (2000) just assumed that value. Applying that value for *M* here, the predicted production averaged over the years since 1990 is 37, 23 and 8 ton for Mälaren, Vänern and Hjälmaren - while the actual fishing yield was 40, 21 and 19 ton. That is: the observed catch exceeds the predicted production. Obviously, the value of *M*=0.1385 is too high. In addition, the efficiency of the fishery is probably less than 100%: not all silver eels produced will have been caught. The actual production must have exceeded the reported catch considerably. This worsens the mismatch between predicted production and observed catch even further. Finally, natural recruits will have added to the stock being exploited, which might explain some of the observed mismatch, but the contribution of natural recruits to the catch is only 10% or less.

Figure 21 (below) details the relation between natural mortality *M* and the corresponding predicted production. For *M*=0.13 (Mälaren), 0.15 (Vänern) and 0.07 (Hjälmaren), the predicted production would exactly match the observed catch, but that would assume that all eels are captured.

In the remainder of this Appendix and the main report, results will be presented for two arbitrary chosen values of *M*, notably *M*=0.05 and *M*=0.10 (Figure 22).

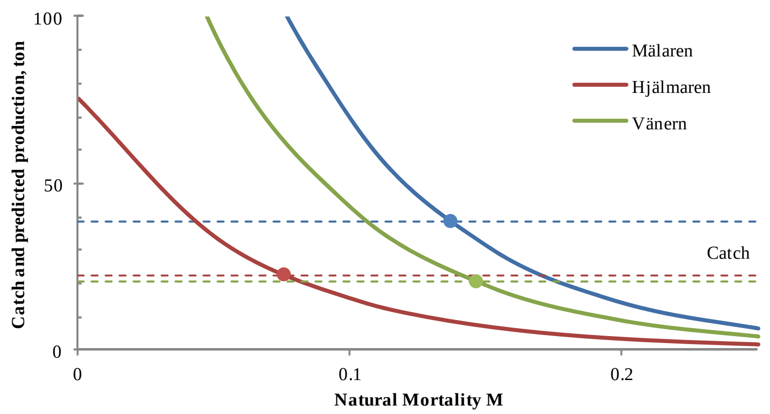


Figure 21 Predicted production as a function of the assumed natural mortality. Production is predicted from the quantities restocked; average for the years 1990-present. The actually observed mean catch over those years is given as a reference (thin dashed lines).

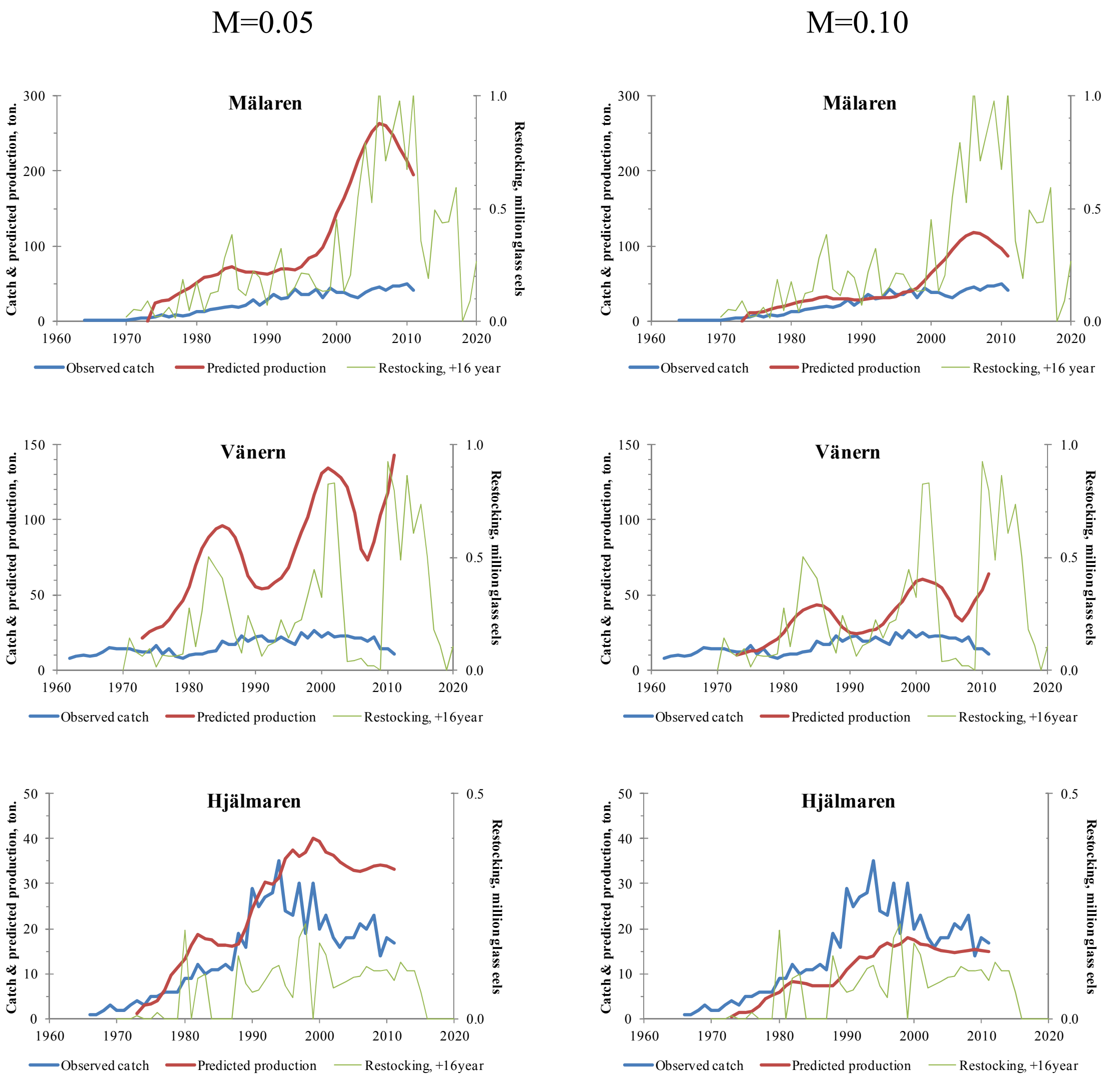


Figure 22 Restocked number of glass eel equivalents (forward shifted by 16 years), predicted production and observed catch, assuming a low (left) and high (right) natural mortality M.

Table 16 Break-down of landings by year and lake, in ton. Estimates in italics have been reconstructed on the basis of the annual totals, assuming a constant fishing mortality per year, making the catch proportional to the predicted production taking into account the actual restockings in the years before. For the years 2010 and 2011, the actual distribution of catches is also shown. (To protect the privacy of individual fishers, most lake names are anonymous. Table 15 uses identical codes).

	Lake a	Lake b	Lake c	Lake d	Lake f	Hjälmaren	Lake i	Mälaren	Lake k	Lake m	Lake p	Lake q	Lake r	Lake s	Lake u	Vänern	Vättern	Lake v	Lake w	Total
1986	*3.4*	*0.1*	*1.9*	*0.5*	*0.6*	12.0	*5.8*	18.0	*0.0*	*4.9*		*13.4*	*2.6*	*1.5*		17.0	*3.2*	*6.2*	*0.8*	92.0
1987	*2.6*	*0.2*	*2.4*	*0.4*	*0.8*	11.0	*4.2*	22.0	*0.0*	*4.5*	*0.0*	*9.3*	*2.4*	*1.4*	*0.0*	17.0	*2.8*	*6.2*	*0.8*	88.0
1988	*4.3*	*0.7*	*5.5*	*0.6*	*2.0*	19.0	*7.1*	28.0	*0.1*	*7.4*	*0.0*	*14.5*	*3.7*	*2.5*	*0.0*	23.0	*3.8*	*12.2*	*1.8*	136.0
1989	*3.4*	*0.8*	*4.6*	*0.6*	*2.2*	16.0	*5.2*	21.0	*0.2*	*5.9*	*0.0*	*11.0*	*2.6*	*2.0*	*0.0*	19.0	*2.2*	*11.1*	*1.2*	109.0
1990	*2.9*	*0.7*	*4.1*	*0.8*	*2.4*	29.0	*3.7*	28.0	*0.3*	*6.5*	*0.0*	*8.4*	*2.2*	*2.2*	*0.0*	22.0	*1.9*	*11.7*	*0.9*	128.0
1991	*2.9*	*0.5*	*6.1*	*1.0*	*2.2*	25.0	*2.9*	35.0	*0.7*	*7.2*	*0.0*	*7.0*	*1.7*	*2.7*	*0.0*	23.0	*1.9*	*11.0*	*1.1*	132.0
1992	*3.7*	*0.4*	*10.4*	*1.2*	*2.2*	27.0	*2.7*	30.0	*1.4*	*8.1*	*0.1*	*6.9*	*1.2*	*3.6*	*0.0*	19.0	*1.6*	*11.0*	*1.5*	132.0
1993	*3.9*	*0.4*	*11.9*	*0.9*	*1.7*	28.0	*1.9*	31.0	*1.8*	*7.0*	*0.1*	*6.0*	*0.9*	*2.9*	*0.1*	19.0	*1.3*	*8.7*	*1.4*	129.0
1994	*6.4*	*0.4*	*19.0*	*1.2*	*2.2*	35.0	*2.3*	43.0	*3.1*	*8.5*	*0.3*	*8.1*	*1.4*	*3.9*	*0.3*	22.0	*1.4*	*10.0*	*2.7*	171.0
1995	*4.5*	*0.2*	*13.8*	*1.0*	*1.4*	24.0	*1.5*	36.0	*2.3*	*5.4*	*0.3*	*5.3*	*1.0*	*2.6*	*0.3*	19.0	*0.8*	*5.4*	*2.5*	127.0
1996	*3.0*	*0.1*	*9.9*	*0.6*	*0.8*	23.0	*0.9*	35.0	*1.7*	*3.7*	*0.2*	*3.6*	*0.8*	*1.5*	*0.3*	17.0	*0.4*	*3.0*	*2.3*	108.0
1997	*3.9*	*0.1*	*14.5*	*0.7*	*0.9*	30.0	*1.1*	43.0	*2.4*	*4.8*	*0.3*	*4.7*	*1.5*	*1.8*	*0.4*	25.0	*0.6*	*3.3*	*3.9*	143.0
1998	*3.5*	*0.0*	*12.9*	*0.7*	*0.9*	19.0	*0.9*	31.0	*2.1*	*4.3*	*0.4*	*4.2*	*1.7*	*1.5*	*0.5*	21.0	*0.3*	*2.7*	*4.4*	112.0
1999	*3.2*	*0.0*	*11.2*	*0.8*	*0.9*	30.0	*0.8*	44.0	*2.1*	*4.9*	*0.7*	*4.2*	*1.7*	*1.2*	*0.5*	26.0	*0.1*	*3.0*	*4.7*	140.0
2000	*2.2*	*0.0*	*9.0*	*0.8*	*0.9*	20.0	*0.6*	38.0	*1.9*	*4.9*	*0.7*	*3.1*	*1.3*	*1.0*	*0.5*	22.0	*0.1*	*3.4*	*3.6*	114.0
2001	*1.7*	*0.0*	*8.3*	*0.8*	*1.0*	23.0	*0.5*	38.0	*1.9*	*5.3*	*0.8*	*2.4*	*1.1*	*1.0*	*0.5*	25.0	*0.1*	*3.7*	*3.1*	118.0
2002	*1.4*	*0.0*	*6.9*	*0.8*	*1.0*	18.0	*0.5*	34.0	*1.9*	*4.9*	*0.8*	*2.0*	*0.9*	*1.0*	*0.4*	22.0	*0.0*	*3.7*	*2.7*	103.0
2003	*1.1*		*5.5*	*0.9*	*1.1*	16.0	*0.5*	31.0	*1.9*	*4.4*	*0.9*	*1.8*	*0.8*	*0.9*	*0.4*	23.0	*0.0*	*3.7*	*2.3*	96.0
2004	*1.0*		*5.6*	*1.1*	*1.3*	18.0	*0.5*	38.0	*2.2*	*4.9*	*1.2*	*1.6*	*0.6*	*1.1*	*0.3*	23.0	*0.0*	*4.2*	*2.1*	107.0
2005	*0.8*		*5.7*	*1.3*	*1.5*	18.0	*0.6*	42.0	*2.3*	*5.5*	*1.4*	*1.3*	*0.4*	*1.3*	*0.4*	21.0	*0.0*	*4.4*	*1.9*	110.0
2006	*0.9*		*7.1*	*1.7*	*1.9*	21.0	*0.9*	45.0	*2.8*	*7.1*	*1.7*	*1.8*	*0.5*	*1.7*	*0.5*	21.0		*5.0*	*2.5*	123.0
2007	*0.8*		*7.0*	*1.4*	*1.5*	20.0	*0.7*	41.0	*2.0*	*6.5*	*1.3*	*1.9*	*0.2*	*1.3*	*0.5*	19.0		*3.6*	*2.4*	111.0
2008	*0.7*		*5.2*	*0.8*	*0.8*	23.0	*0.4*	47.0	*0.9*	*4.7*	*0.8*	*1.3*	*0.1*	*0.7*	*0.4*	22.0		*1.9*	*1.4*	112.0
2009	*0.9*		*6.1*	*0.6*	*0.6*	14.0	*0.4*	47.0	*0.7*	*5.3*	*0.6*	*1.5*	*0.1*	*0.6*	*0.4*	14.0		*1.7*	*1.5*	96.0
2010	*1.1*		*8.4*	*0.6*	*0.6*	18.0	*0.4*	49.0	*0.8*	*7.2*	*0.6*	*2.0*	*0.3*	*0.6*	*0.5*	14.0		*2.1*	*1.9*	108.0
2011	*0.5*		*4.9*	*0.3*	*0.3*	17.0	*0.2*	42.0	*0.4*	*4.0*	*0.3*	*1.2*	*0.2*	*0.3*	*0.3*	11.0		*1.2*	*1.0*	85.0
Actual																				
2010	0.3	0.4	4.2	0.3	0.2	18.1	1.2	49.1	0.2	6.3	0.2	0.4	0.4	0.2		13.9	0.1	3.6	8.3	107.3
2011	0.1		1.5	0.4	0.4	16.7	1.1	41.7	0.2	7.9	0.2			0.2	0.4	11.0		2.6		84.2

Reconstructing trends and fishing yield per lake

The trend in landing statistics is presented in section 2.2.1 of the main report, giving time series for the great lakes, and for the sum of all other lakes. In order to differentiate between lakes with many/few eels being restocked and/or low/high number of power-stations downstream, an estimate of the catch by lake is required. For the great lakes Mälaren, Hjälmaren and Vänern, historical time series started in the 1960s. For all other lakes, only the total for the whole country is known since 1986; for the years 2010 and 2011, a detailed break-down by lakes is available. Table 16 combines available data and a reconstruction. This reconstruction is based on the assumption that relative fishing impact (the catch expressed as a percentage of the stock at large) has been constant over all lakes, that the fishery is equally efficient in all lakes, that fishing mortality is a constant per year. The spatial distribution in earlier years will deviate from that found in 2010/2011, because of the shift in the spatial distribution of restockings, as reflected in the current reconstruction.

Assessing the impact of fishing and hydropower generation

The assessment of the impacts of fishing and hydropower generation proceeds as follows:

1. For each batch of young eels that has been restocked since 1970, the equivalent number of glass eels has been calculated. This involves both a change in number and a backward shift in the year to which the restocking is assigned. For elvers (yngel) purchased abroad and quarantined, an average age at restocking of one year was assumed; for bootlace eels (trollål) from Trollhättan, two years; and for eels from the West Coast (sättål), six years. For West Coast sättål, for instance, the number was raised to number × exp(+6*M), and the year of restocking as glass eel set at year-6. In the remainder of this calculation, all restockings are expressed in glass eel equivalents, standardizing the forward projection. When projected forward in time, the glass eel equivalents first grow to the size at which they were actually stocked, while their numbers decline due to natural mortality. Thus, this forward projection ends up with exactly the number and age of the restocked eels in the right year.

2. For each batch of eels in the database of restockings, the number, year, size and place of release are specified. This is used to predict the quantity of silver eels a lifetime later, using the formulae given above. Note that a single batch might contribute to the silver eel production in up to 21 different years.

3. For each lake and year, the catch is subtracted, using a figure in accordance with Table 16. Note that Table 16 is based on the total annual landings in combination with the predicted production (point 2 above). Hence, the predicted production always exceeds the reconstructed catch.

4. In accordance with the assessment in the Eel Management Plan, the impact of hydropower generation plants on the silver eel run is estimated from a GIS database of hydropower plant locations. This database was the same as used in 2008. In accordance with the Eel Management Plan, an average mortality of 70% per hydropower station was assumed.

5. Finally, the number of surviving eels escaping to the sea is left.

$$Escapement = (predictedProduction - reconstructedCatch) \times exp^{numberPowerstations \times log(30\%)}$$

Note that the contribution of Trap & Transport of silver eel to the total escapement is treated separately.

Medium term projection

In 2010 and 2011, quantities of young eels being restocked have increased and the spatial distribution of the restockings has shifted to westward flowing rivers, supposed to have less impact of hydropower generation plants. These changes happening in 2010/2011, their full effect is expected to influence the silver eel escapement in the late 2020s only. As a consequence, these actions are not directly reflected in the current post-evaluation. ICES (2011) therefore recommends to make medium-term projections, that is: forward projections over the period of time that the stock is dominated by the yearclasses that are already present and that currently taken management measures will get their full effect. For restocking, the medium term projecting follows the above calculation of predicted production exactly, taking into account the quantities and locations as actually used in the years up to 2011. These restockings will contribute to the stock until the end of the 2020s. At the end of the 2020s, however, the stock will also contain a contribution from later restockings. It was therefore assumed that the 2011 restocking programme will be replicated in full detail (quantity, location, size of restocked eels) in the coming years. For the impact of the fishery and of hydropower, it is assumed that relative impacts will remain unchanged after 2011; that fishing mortality and hydropower mortality are constant and that the spatial distribution of fishing effort and hydropower generation plants does not change. Due to the recent changes in the restocking programme, the actual quantity of eels being influenced by fishing or hydropower impacts will change, but not their percent-wise impact. The medium term projections thus reflect the delayed effect of today's restocking, not of potential future restrictions to the fishery or improvement of survival through hydropower generation plants.

Results of the medium term projections are shown for three years:

- 2012, showing the effect of the peak in restockings in the late 1990s;
- 2020, showing the effect of the lower restocking in the mid-2000s;
- 2030, showing the full effect of the current, increased, west-ward shifted restockings.

Results and discussion

The assessment described above was designed to adequately represent the temporal trend and spatial distribution of restocking, of fisheries and of hydropower impacts. Though both the spatial and temporal patterns are based on observations, it is unlikely that estimates are reliable down to the level of individual lakes in individual years. Therefore, only the general patterns are shown. Figure 23 shows the temporal trend in impacts and escapement in terms of biomass, while Figure 25 expresses the same in terms of mortality rates. Figure 27 shows the spatial distribution of biomasses for three selected years, while Figure 29 combines all locations having an equal number of power stations downstream. Finally, all plots show estimates based on a low (M=0.05, left) or high (M=0.10, right) value assumed for natural mortality.

In the late 1990s, restocked quantities peaked (Figure 10) at ca. 3 million glass eel equivalents. Due to the long lifespan of the eel, this is expected to lead to a maximum in predicted production only by 2012 (Figure 23). In later years restocking declined, and consequently, a diminishing production in inland waters is foreseen for the coming years, up to the early 2020s. Since the implementation of the Eel Management Plan, restocking levels have reached 2 million again, which will have an effect on the production of silver eels at the end of the 2020s. These recent restockings are concentrated in west-ward flowing rivers, with a lower fishing pressure. As a consequence, the fishing impact is expected to decline, even after 2020. The impact of hydropower, however, will follow the trend in production and increase to its current level, unless additional measures are taken. Net escapement from inland waters is predicted to follow the declining stock trend until 2020, but not to recover afterwards. Though the absolute quantities predicted are sensitive to the assumed level of natural mortality, these temporal trends hardly are.

The corresponding trends in mortality (Figure 25) show a declining impact of the fishery, and an increasing impact of hydropower generation. Note that these predictions assume that current practices are continued as-is, and no additional management measures are taken. Additionally, the effect of Trap & Transport of silver eels has not been taken into account here. However, noting that the silver eels for the Trap & Transport programme are currently derived from the commercial fishery, the (positive) effect of Trap & Transport cannot exceed the (negative) impact of the fishery. Hence, this programme cannot be expanded to a level that would stop the increasing trend in total impacts.

The spatial distribution of restockings (Figure 12) and predicted production (Figure 27) is, to a large extent, dominated by a few larger lakes: first and foremost Mälaren and Vänern. Over the years, restocking into these lakes has declined, but following the implementation of the Eel Management Plan, restocking into Vänern has been increased to more than the historical level.

Lake Vänern has currently three hydropower stations downstream (Figure 29), with an expected survival of $(30\%)^3$ = 3%, while Mälaren has no hydropower stations downstream. The current shift in restocking from Mälaren to Vänern is the main factor explaining the declining fishing and increasing hydropower impacts assessed. Direct measurements of survival of tagged silver eels from Vänern (Lagenfelt, in prep.) indicate a higher survival of up to ca. 30 % over the three power stations – that is approx. 67% survival per power station. This indicates that a standard assumption of 30% survival per hydropower station is an over-simplification of reality. A more detailed assessment is required, which is not achievable within the current time frame. However, assuming a general survival as high as 67% for all hydropower stations all over the country, the spatial and temporal trends do not differ markedly from the ones sketched above: a decreasing impact of the fishery, a stabilising/increasing impact of hydropower generation and a declining escapement until 2020 followed by a restoration to the current (low) value.

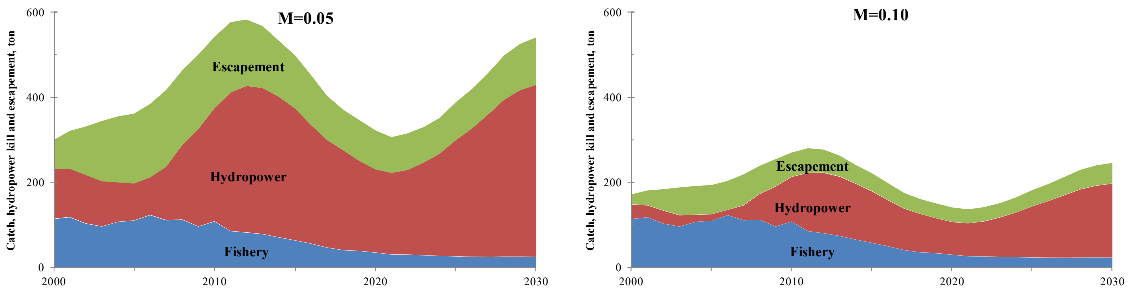


Figure 23 Estimated trends in fishing yield, hydropower mortality and silver eel escapement, assuming a low (left) and high (right) natural mortality M, for a mortality of 70% per hydropower station as assumed in the Eel Management Plan. For the years after 2011, it is assumed that the fishing and hydropower generation related mortalities remain stable at their current level, while the delayed effects of current restocking (increased quantities with a changing spatial distribution) slowly move in.

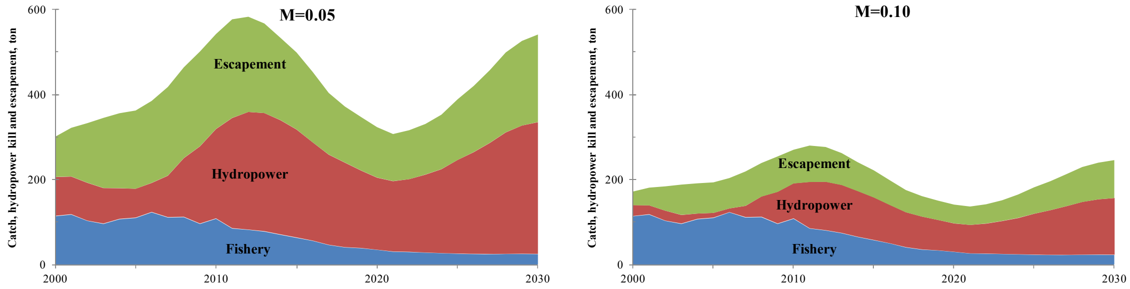


Figure 24 Estimated trends in fishing yield, hydropower mortality and silver eel escapement, assuming a low (left) and high (right) natural mortality M, for a mortality of 33% per hydropower station as indicated by recent experiments in Lake Vänern.

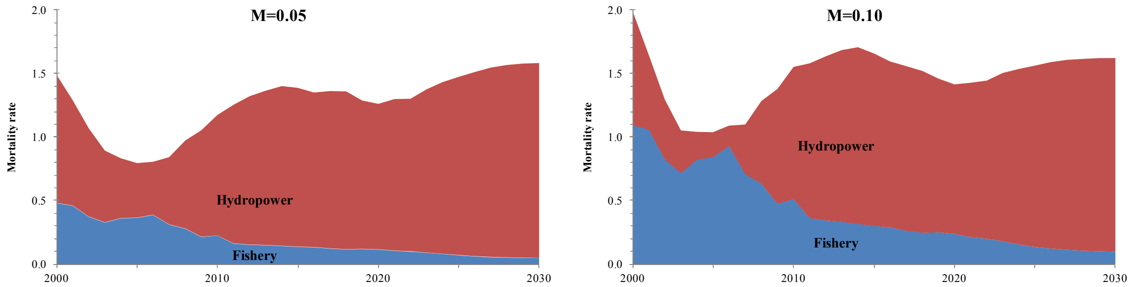


Figure 25 Estimated trends in fishing mortality and hydropower mortality, assuming a low (left) and high (right) natural mortality M, for a mortality of 70% per hydropower station as assumed in the Eel Management Plan. For the years after 2011, it is assumed that the fishing and hydropower generation related mortalities remain stable at their current level, while the delayed effects of current restocking (increased quantities with a changing spatial distribution) slowly move in.

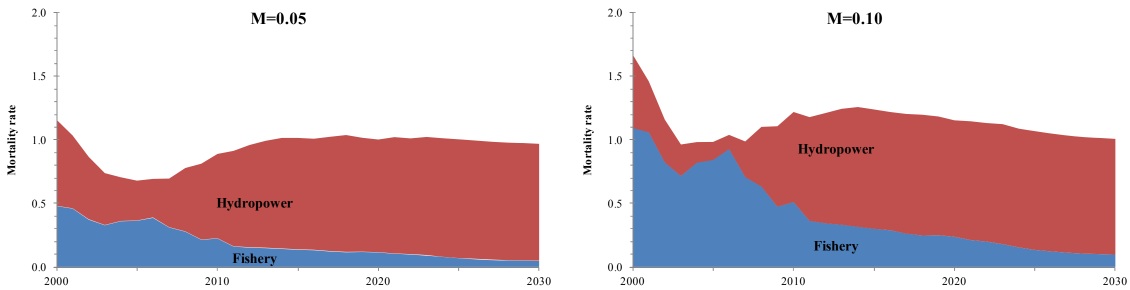


Figure 26 Estimated trends in fishing mortality and hydropower mortality, assuming a low (left) and high (right) natural mortality M, for a mortality of 33% per hydropower station, as indicated by recent experiments in Lake Vänern.

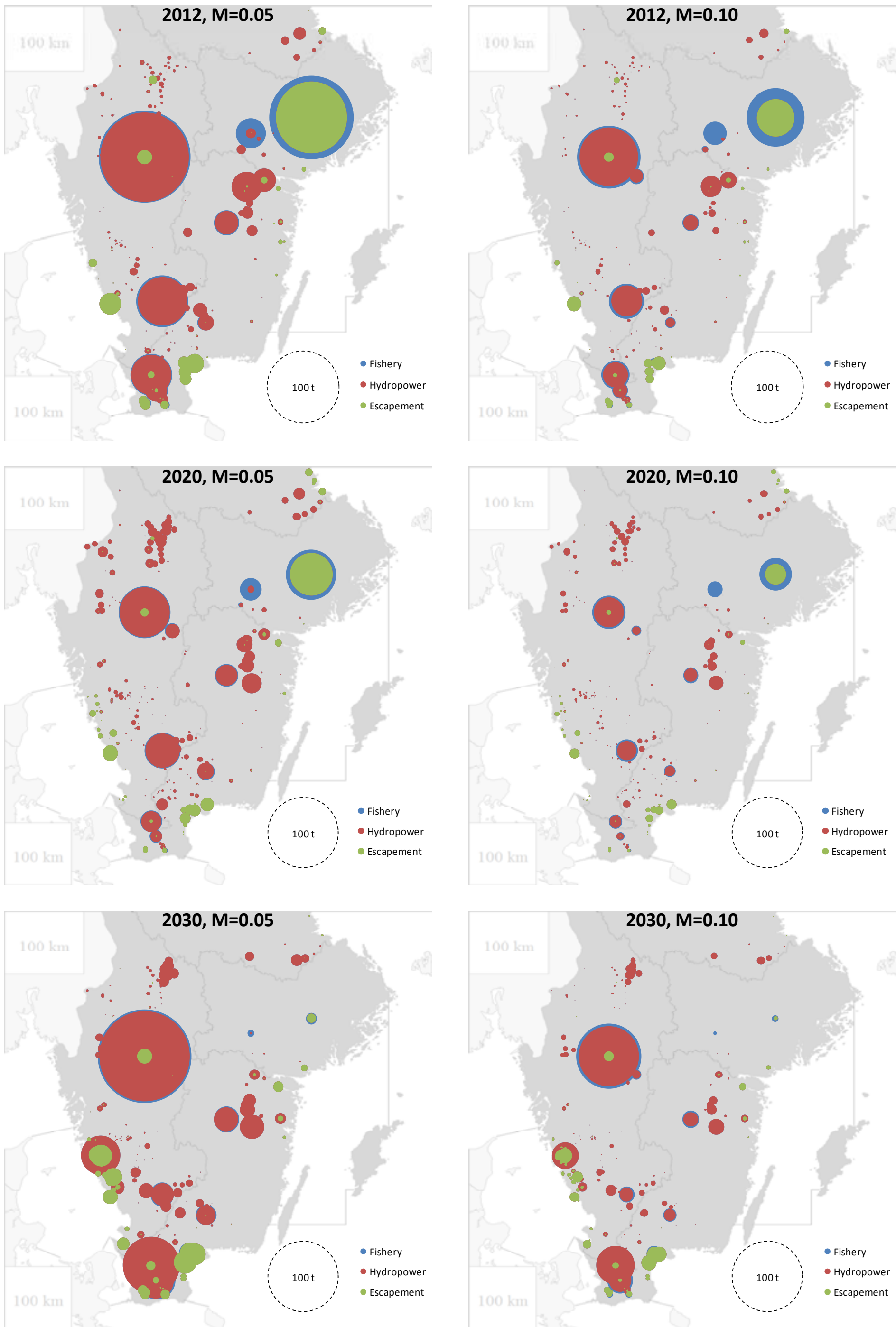


Figure 27 Inland production of silver eel (bubble size), predicted on the basis of the number of eels restocked, broken down by mortality factor (fishery or hydropower related) and escapement. By 2012, the peak in restocking from the late 1990s is dominating; by 2020, the 2000s low is; and by 2030, the full effect of today's restocking (2011) is reached. Results are sensitive to the assumed natural mortality; panels to the left assume a low natural mortality; panels to the right a high natural mortality. In predicting future production and mortality, all parameters except the restocking (quantity and distribution) have been kept constant. These results are based on <u>a mortality of 70% per hydropower station</u>, as assumed in the Eel Management Plan.

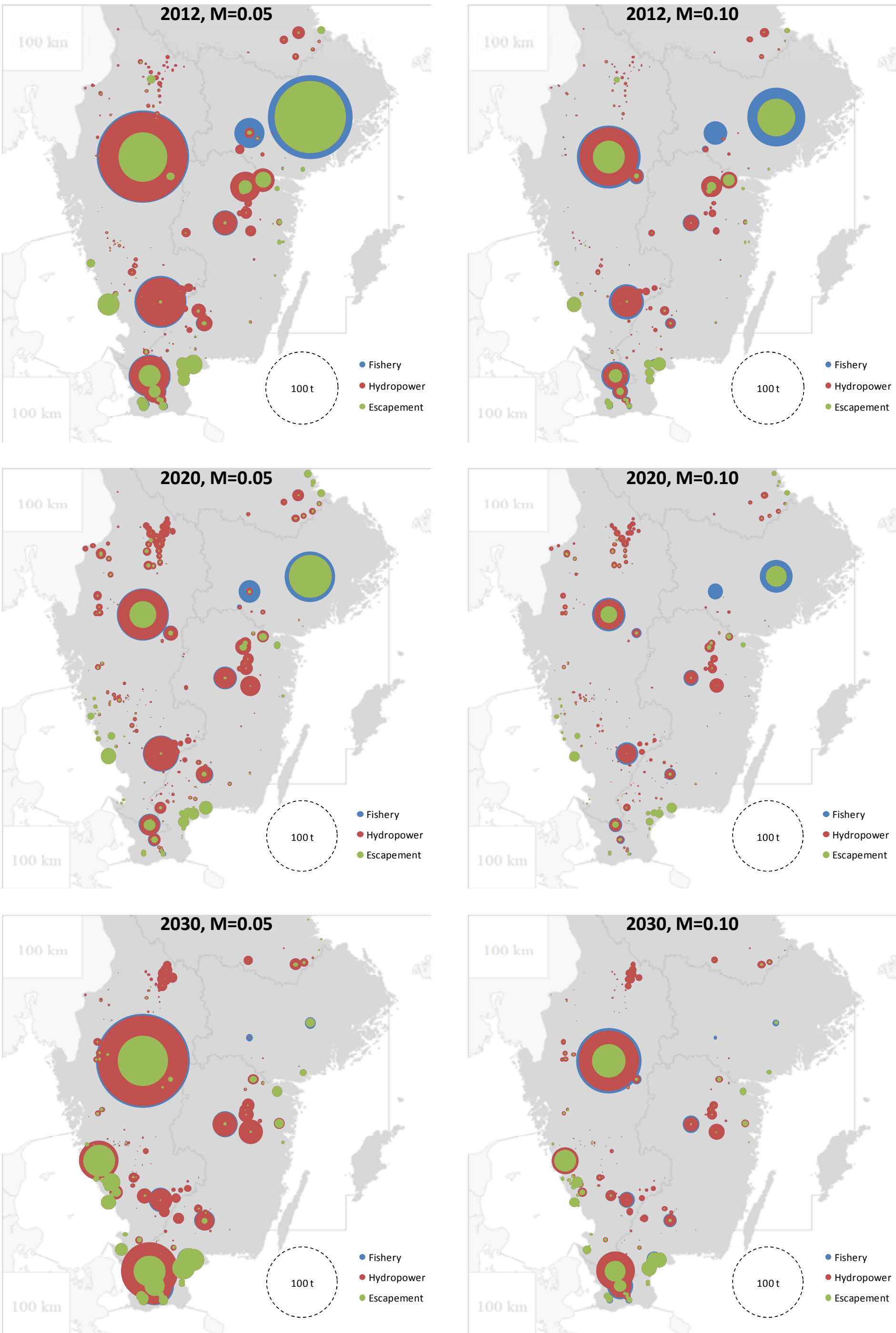


Figure 28 Inland production of silver eel (bubble size), predicted on the basis of the number of eels restocked, broken down by mortality factor (fishery or hydropower related) and escapement. See previous figure for further details. These results are based on <u>a mortality of 33% per hydropower station</u>, as indicated by recent experiments in Lake Vänern.

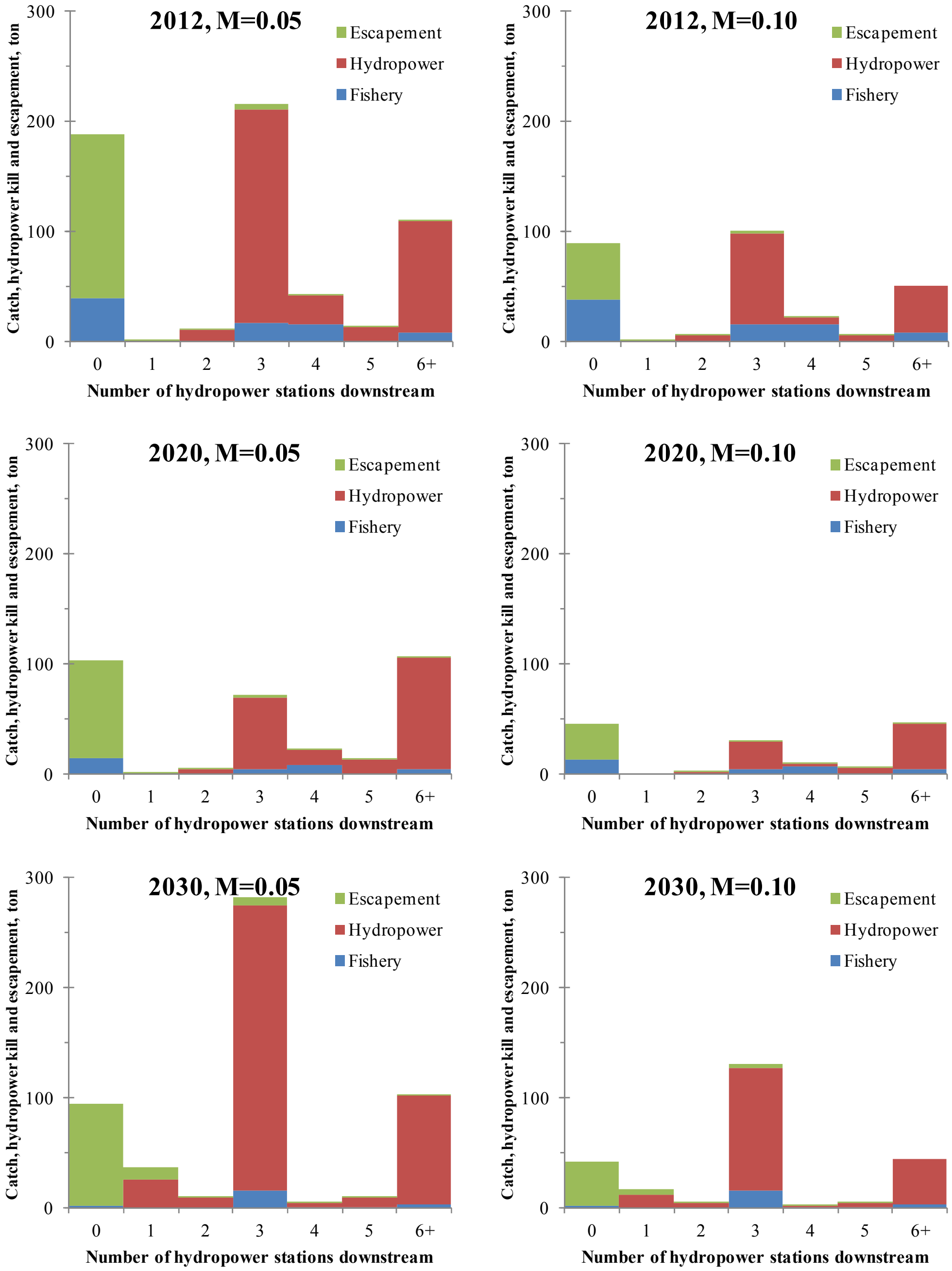


Figure 29 Inland production of silver eel broken down by the number of power stations downstream of the location where the eels were originally restocked. The arrangement of this figure is the same as in Figure 27; see there for further explanation. These results are based on <u>a mortality of 70% per hydropower station</u>, as assumed in the Eel Management Plan.

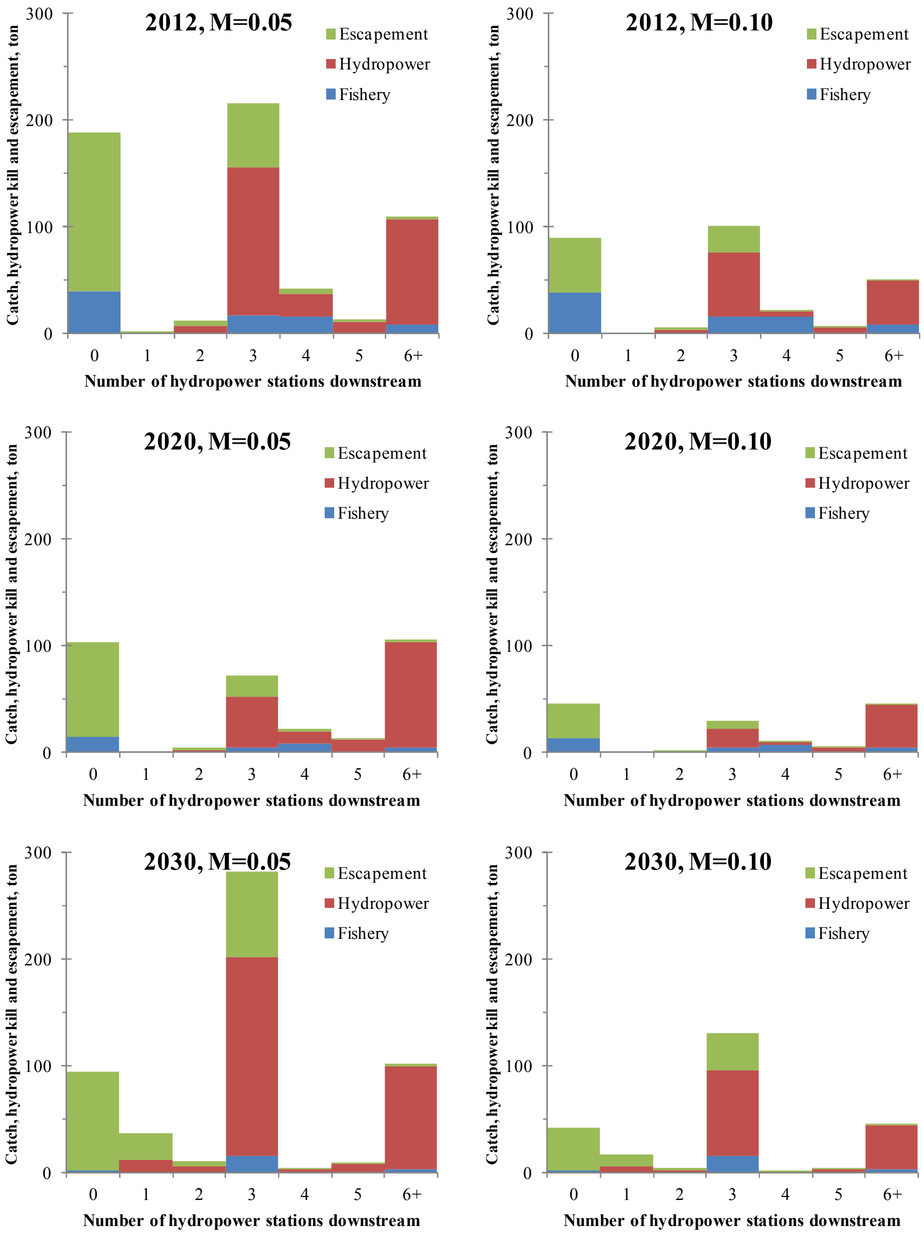


Figure 30 Inland production of silver eel broken down by the number of power stations downstream of the location where the eels were originally restocked. The arrangement of this figure is the same as in Figure 27; see there for further explanation. These results are based on a mortality of 33% per hydropower station, as indicated by recent experiments in Lake Vänern.