Evaluation of the Dutch Eel Management Plan 2015: status of the eel population in the periods 2005-2007, 2008-2010 and 2011-2013.

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Summary (in Dutch)

Evaluatie van het Nederlandse aalbeheerplan: maatregelen hebben in eerste instantie geleid tot een substantiële verbetering van de overleving tussen de perioden 2005-2007 en 2008-2010 gevolgd door een bescheiden verbetering in overleving tussen de perioden 2008-2010 en 2011-2013; positieve effecten op de aalpopulatie kunnen pas na vele jaren zichtbaar worden en blijven onzeker, omdat de aal pas na vele jaren terug zwemt naar zee om zich voort te planten en omdat niet goed bekend is welke de oorzaken zijn van de achteruitgang in de aalpopulatie.

Het gaat slecht met de aal in Europa

De aalpopulatie en aalvangsten zijn sterk teruggelopen: De huidige intrek van glasaal is slechts ~5% van de intrek in de 60-70-er jaren. Deze situatie is zorgwekkend en wordt door de International Council for the Exploration of the Sea (ICES) in 2014 als volgt omschreven: *"The status of eel remains critical and ICES advises that all anthropogenic mortality (e.g. recreational and commercial fishing, hydropower, pumping stations, and pollution) affecting production and escapement of silver eels should be reduced to – or kept as close to – zero as possible.*"

Maatregelen voor aalherstel

Om herstel van de aalpopulatie mogelijk te maken heeft De Raad van de Europese Unie in 2007 de "EU Regulation for the Recovery of the Eel Stock (EC 1100/2007)" vastgesteld. Deze verordening verplicht de lidstaten om met een eigen nationaal aalbeheerplan te komen en te implementeren. Het doel van deze aalbeheerplannen is daarbij als volgt omschreven: "Doel van de beheersplannen voor aal is het verminderen van de antropogene sterfte, zodat er een grote kans bestaat dat ten minste 40% van de biomassa van schieraal kan ontsnappen naar zee, gerelateerd aan de beste raming betreffende de ontsnapping die plaats zou hebben gevonden indien de mens geen invloed had uitgeoefend op het bestand. De beheersplannen voor aal worden opgesteld met het oog op het bereiken van die doelstelling op lange termijn."

Lidstaten zijn verplicht om voor de tweede maal over de voortgang van de nationale aalbeheerplannen te rapporteren aan de Europese Commissie, voor 1 juli 2015. Tegen deze achtergrond heeft Nederland een eigen aalbeheerplan opgesteld en geïmplementeerd in juli 2009. De onderliggende rapportage betreft een evaluatie van de effecten van het Nederlandse aalbeheerplan tot op heden, als bijdrage aan de rapportage aan de Europese Commissie.

Aalbeheerplan Nederland

Het aalbeheerplan van Nederland omvat de volgende maatregelen:

Nr	Maatregelen op tijd geïmplementeerd	Geplande implementatie	Gerealiseerde implementatie
1	Terugzetten van aal (a) op zee en (b) op binnenwater door sportvissers	2009	1 oktober 2009
2	Verbod op recreatieve visserij, gebruikmakend van professionele vistuigen.	2011	1 januari 2011[a]
3	Gesloten aalvisseizoen 1 september tot 1 december	2009	1 oktober 2009[b]
4	Stoppen met uitgave van peurvergunningen op Staatswateren.	2009	1 mei 2009
5	Onderzoek naar het kweken van aal in gevangenschap.	doorlopend	EU-project
6	Oplossen van migratieknelpunten bij sluizen, gemalen en andere kunstwerken; van de 1800 belangrijkste knelpunten worden 900 opgelost voor 2015 de overige 900 voor 2027.	2015-2027	2015-2027[c]
7	Aangepast turbinebeheer bij de drie grote waterkrachtcentrales, veminderen sterfte met minstens 35%	2009	17 november 2011[d]
8	Visserijvrije zones in gebieden die belangrijk zijn voor aalmigratie.	2010	1 April 2011[e]
9	Uitzet van glas- en pootaal.	2009	Start 2010, daarna doorlopend.
10	Sluiten van de visserij in de belangrijkste grote rivieren, met als aanleiding dioxineverontreiniging.		1 April 2011[f]

[a] *Het gebruik van fuiken en staand want in de recreatieve visserij in de kustgebieden is verboden sinds 1 januari 2011. Op 1 januari 2012 is staand want in de Waddenzee en Westerschelde weer toegestaan. En in mei 2012 ook weer in de Noordzee. Reden hiervoor is dat met staand want geen aal gevangen wordt.*

[b] *In 2009 twee maanden gesloten, oktober en november, vanaf 2010 drie maanden gesloten (oktober-december.*

[c] *Door de taakstelling uit het regeerakkoord zijn een aantal maatregelen in het hoofdwatersysteem getemporiseerd tot na 2015.*

[d] *Om technische redenen blijkt een effect van 24% maximaal mogelijk.*

[e] *Vanwege het sluiten van de belangrijkste grote rivieren (maatregel 10), die dienst doen als “migratie snelwegen” is besloten deze maatregel niet meer in te voeren. Het besluit is genomen op grond van een wetenschappelijke analyse.*

[f] *Per 1 april 2011 grote gebieden gesloten (vooral de grote rivieren) voor de aalvisserij omdat de aldaar gevangen aal niet voldeed aan eisen rond voedselveiligheid door te hoge gehalten aan PCB’s en dioxines. Deze maatregel was geen onderdeel van het oorspronkelijke aalbeheerplan, maar is later toegevoegd.*

Evaluatie van het aalbeheerplan Nederland

Het aalbeheerplan is geëvalueerd in het licht van de voornoemde “beheerdoelen” uit de Aalverordening. De methodiek die bij deze evaluatie is gehanteerd komt voort uit de ICES - “werkgroep aal” (http://www.ices.dk/community/groups/Pages/WGEEL.aspx).
Dit betekent dat in deze evaluatie alleen wordt ingegaan op de effectiviteit van maatregelen in relatie tot beheerdoelen opgesteld door de Raad van de Europese Unie. In hoeverre deze beheerdoelen ook in lijn zijn met het voorzorgprincipe of duurzaam beheer volgens ICES-ACOM is niet aan de orde.
De evaluatie is uitgevoerd door middel van modellen, vangstgegevens, veldwaarnemingen en statistische analyses, uitvoerig beschreven in de rapportage. Het geheel van deze inspanning resulteerde in schattingen *voor* (2005-2007) en *na* (2008-2010, 2011-2013) de implementatie van het Aalbeheerplan van, met name:

- De biomassa uittrekkende schieraal: 897 t in 2005-2007, 1035 t in 2008-2010 en 1057 t in 2011-2013.
- De pristine biomassa (B_0) aan uittrekkende schieraal: 10.400 t (exclusief zee- en kustwateren).
- De doelstelling van de Aalverordening voor Nederland: 4160 ton (40% van de pristine biomassa (B_0); exclusief zee- en kustwateren).
- De uittrek van schieraal t.o.v. deze doelstelling: 22% in 2005-2007, 25% in 2008-2010 en 25% in 2011-2013.
- De reductie in antropogene sterfte door de genomen maatregelen: de antropogene sterfte van glasaal naar schieraal is afgenomen van 72% in 2005-2007 en 46% in 2008-2010 naar 38% in 2011-2013.

Deze schattingen zijn ruw, en de daarmee gepaard gaande onzekerheid is in de rapportage omschreven.

Effecten van het Nederlandse aalbeheerplan op de Nederlandse aalpopulatie

De evaluatie laat zien dat de maatregelen uit het Nederlandse beheerplan aal hebben geleid tot een substantiële teruggang in sterfte door menselijk handelen tussen 2005-2007 en 2008-2010. Deze reductie was voornamelijk het gevolg van beperkingen van de visserij (recreatief en beroep). Tussen 2008-2010 en 2011-2013 is een verdere bescheiden teruggang in (visserij) sterfte door menselijk handelen gerealiseerd. Door aanpassingen aan de infrastructuur bij migratieknelpunten is de *relatieve* sterfte in 2011-2013 afgenomen (i.e. de kans dat een aal sterft tijdens passeren van een migratieknelpunt) maar door de toename in de hoeveelheid schieraal die tijdens de migratie een knelpunt (b.v. gemaal, WKC) moet passeren lijkt de *absolute* sterfte door barrières te zijn toegenomen.

De status van aal in de Nederland blijft in 2011-2013 “ongewenst” (hoge sterfte, lage biomassa); de huidige biomassa van uittrekkende schieraal ligt onder de doelstelling van minimaal 40% van de pristine biomassa (B_0) (exclusief zee- en kustwateren) en de huidige sterfte door menselijk handelen ligt boven de geadviseerde sterfte bij een dergelijke lage biomassa aan uittrekkende schieraal.

De aalpopulatie in Nederland en de uittrek van schieraal zullen pas veel later substantieel verbeteren. De reden dat dit zo lang duurt is dat aal een langlevende soort is. Het duurt meer dan een jaar voordat glasaal na geboorte aankomt voor de Nederlandse kust en de binnenwateren op zwemt. Vervolgens duurt het 5-15 jaar voordat deze aal “schier” wordt, en als schieraal terugtrekt naar zee.
Het blijft verder onzeker of de genomen maatregelen op termijn werkelijk zullen leiden tot een duurzaam verbeterde aalstand, omdat niet zeker is welke factoren de achteruitgang in de aalstand hebben veroorzaakt.

1. Introduction

1.1 Stock indicators for evaluation of the Dutch Eel Management Plan

Scientific advice from the International Council for the Exploration of the Sea (ICES) concerning European eel was that the stock was outside safe biological limits and that current fisheries were not sustainable. ICES recommended that a recovery plan be developed for the whole stock of European eel as a matter of urgency and that exploitation and other human activities affecting the fishery or the stock be reduced as much as possible. In response to this advice the EU Regulation for the Recovery of the Eel Stock (EC 1100/2007) was adopted in 2007. It required Member States (MS) to set up an Eel Management Plan (EMP) by the end of 2008 (article 2); " *The objective of each Eel Management Plan shall be to reduce anthropogenic mortalities so as to permit with high probability the escapement to the sea of at least 40 % of the silver eel biomass relative to the best estimate of escapement that would have existed if no anthropogenic influences had impacted the stock. The Eel Management Plan shall be prepared with the purpose of achieving this objective in the long term."*

Nineteen MS have submitted EMPs, six MS were exempted from the obligation to establish EMPs as their territory was deemed not to constitute significant eel habitat and two MS did not submit EMPs, and were thus obliged by default to implement a 50% reduction in eel fisheries. In the Netherlands the Eel Management Plan was implemented in July 2009. An overview of the measures regarding the EMP is given in Table 1.1.

The member states had to report for the first time on the progress of the national EMPs to the European Commission (EC) by June 30 2012. The evaluation in 2012 of the Dutch Eel Management Plan demonstrated that before (2008) and after (2011) the implementation of the EMP the status of eel in Dutch waters remained in a situation regarded as “undesirable”, with high mortality and a low biomass (Bierman et al., 2012). In 2011, the biomass of escaping silver eel was below the target of 40% of the pristine situation and the anthropogenic mortality was above the recommended mortality (following the modified precautionary diagram developed by ICES 2011b). Measures to reduce anthropogenic mortality are relatively quick to implement and will directly result in measurable improvements. A reduction in anthropogenic mortality is therefore a good indicator of the drive and prowess of a Member State. In the Netherlands the implementation of the EMP has resulted in a significant decrease in anthropogenic mortality between 2008 and 2011. The observed reduction in anthropogenic mortality was almost solely the result of a decrease in fishery mortality, both commercial and recreational. The remaining measures (hydropower plants, pumping stations etc.) had in 2011 limited measurable impact on a reduction in eel mortality.

Table 1.1 Overview of all the (un)foreseen measures described in the Dutch Eel Management Plan to be implement to reach the 40% escapement objective.

No	Foreseen Measure	Planned implementation	Realised implementation
1	Reduction of eel mortality at pumping stations and other water works; of the 1800 most important migration barriers 900 will be solved by 2015 and the remaining 900 by 2027	2015-2027	2015-2027[a]
2	Reduction of eel mortality at hydro-electric stations with at least 35%	2009	November 2011[b]
3	The establishment of fishery-free zones in areas that are important for eel migration	2010	1 April 2011[c]
4	Release of eel caught (a) at sea and (b) at inland waters by anglers	2009	1 October 2009
5	Ban on recreational fishery in coastal areas using professional gear	2011	1 January 2011[d]
6	Annual closed season from 1 September to 1 December	2009	1 October 2009
7	Stop the issue of licences for eel snigglers by the minister of EZ in state owned waters	2009	1 May 2009
8	Restocking of glass eel and pre-grown eel from aquaculture	2009	Early 2010
9	Research into the artificial propagation of eel	ongoing	EU-project started
	Unforeseen Measure		
10	Closure eel fishery in contaminated (PCBs, dioxins) areas		1 April 2011[e]

[a] In agreement with the European Commission changes have been made to the original schedule of solving migration barriers.

[b] Due to technical difficulties the maximum achievable reduction in mortality by adjusted turbine management is 24%.

[c] The vast majority of the contaminated areas that were closed for commercial fisheries on 1/4/2011 are the main rivers. These rivers are the most important “high ways” for diadromous species like salmon and eel.

[d] The use of fykes and long-lines by recreational fishers has been banned in nearly all marine and inland waters waters. The use of gillnets, however, by recreational fishers is still allowed in a few marine waters.

[e] On 1 January 2015 the area closed for eel fishery due to contaminants (PCBs, dioxins) was extended.

It was proposed by the ICES WGEEL to include an improved set of stock indicators and related data (Table 1.2) in the 2015 progress reports submitted to the European Commission by MS. These stock indicators need to be submitted by the 30th of June 2015. The purpose of the indicators is to render the reports more efficient in demonstrating the progress achieved via the implementation of the eel management plans. In particular, there needs to be a clear indication as to the achievement of the 40% escapement target.

Table 1.2 Overview of the stock indicators and related data to be reported by member states to the EC by the 30th June 2015.

B_0	The amount of silver eel biomass (kg) that would have existed if no anthropogenic influences had impacted the stock. B_0 is in the Regulation, as a denominator for the 40%, and in Art 2.5.
$B_{current}$	The amount of silver eel biomass (kg) that currently escapes to the sea to spawn. $B_{current}$ is in the Regulation, as the nominator of the proportion of silver eel biomass actually escaping, in Art 9.1.a.
B_{best}	The amount of silver eel biomass (kg) that would have existed if no anthropogenic influences had impacted the current stock. B_{best} is not in the Regulation. It could be calculated from $B_{current}$, ΣF and ΣH. In line with the ICES framework this would allow for a cross-check in the interpretation of the quantities above.
ΣF	The fishing (both commercial and recreational) mortality rate (and in kg silver eel equivalents), summed over the age-groups in the stock, and the reduction effected.
ΣH	The anthropogenic mortality rate (and in kg silver eel equivalents) outside the fishery, summed over the age-groups in the stock, and the reduction effected. ΣH is in the Regulation, in Art 9.1.c ("level of mortality factors"). ICES considers that ΣA = ΣF+ΣH.
ΣA	The sum of anthropogenic mortalities, i.e. ΣA = ΣF + ΣH.
R	The amount of glass eel used for restocking within the country. R is in the regulation, in Art 9.1.d, ("the amount of eel less than 12 cm in length caught and the proportions of this utilised for different purposes"). R is not relevant for the Netherlands as no eel smaller than 12 cm is landed, minimum size in the Netherlands is 28 cm.
Wetted Area	Wetted area (ha) of inland waters, transitional waters and marine waters used in B_0, $B_{current}$ and B_{best}
Measures	Provide a 'quantified' overview of implemented measures, i.e. closed season (no. of days), change in quota (kg) etc.

The Ministry of Economic Affairs (EZ) has requested IMARES 1) to provide estimates for the required stock indicators, and 2) to use these indicators to evaluate the impact of the EMP on anthropogenic mortality and biomass of escaping silver eels using the modified ICES precautionary diagram.

1.2 General description of the stock assessment methodology and main data sets

Estimates of both absolute biomass of silver eel escapement and mortality rates are requested by the EC, as listed in Table 1.2. However, for the current evaluation of the EMP, the most important of the required estimates are the anthropogenic mortality rates which, when summed over the age-groups in the stock ($\Sigma A = \Sigma F + \Sigma H$), provide an estimate of the **Lifetime Anthropogenic Mortality, or LAM**. The LAM only refers to the continental part of the life cycle of European eels (see Figure 1.1). Management actions were taken to reduce anthropogenic mortalities immediately, and estimated reductions ('before' compared to 'after' the implementation of the EMP) in LAM can therefore be used to evaluate the success of these management actions. Instead, the impact of management actions on the biomass of silver eel escapement also depends on trends in recruitment. Some measures, in particular reduction of yellow eel mortalities and glass eel stocking, will take at least several years to materialise. Estimates of LAM can be used to put current silver eel escapement ($B_{current}$; Table 1.2) into context, by comparing it with the best possible spawner escapement under recent recruitment conditions (B_{best}). The estimated proportion $B_{current}/B_{best}$, referred to as %SPR (current spawner-per-recruit as a percentage of the best possible spawner-to-recruit ratio; ICES 2014 and references therein), can be compared with the 40% escapement target of the EU eel regulation. Estimated improvements ('before' compared to 'after') in %SPR are therefore an important means by which the EMP can be evaluated. A certain estimated level of LAM will result in a corresponding %SPR. A particular problem in this context is that cohorts that are currently in the stock will all have different lifetime anthropogenic mortality rates, since these rates will have changed over time. However, ICES indicated that estimates of either ΣA or %SPR usually refer to anthropogenic impacts in the most recent year, not to impacts summed over the life history of any individual or cohort in the current stock (ICES 2014 and references therein).

To estimate LAM, we consider anthropogenic mortalities during the two main continental life stages of eels (Figure 1.1):

1) fishing (commercial and recreational) mortalities that occur during the yellow eel stage, and;
2) fishing (commercial) and barrier mortalities that occur during migration as a silver eel.

The reason for considering these two types of mortalities separately is that yellow eel mortalities apply over a sequence of years from transformation as glass eel to yellow eel up until the point of transformation from yellow eel to silver eel. Instead, silver eel mortalities are assumed to apply during a single year in the life cycle of an eel.

To estimate the %SPR for a given level of anthropogenic yellow eel mortality, a demographic model for yellow eels is introduced in this report (Chapter 3) in which the development of glass eel to silver eels is modelled as a function of growth, maturation and natural and anthropogenic mortality. Estimated silver eel mortality rates are assumed to apply only once in the life cycle of eels and result in a reduction of the %SPR as estimated as a function of the current yellow eel anthropogenic mortality.

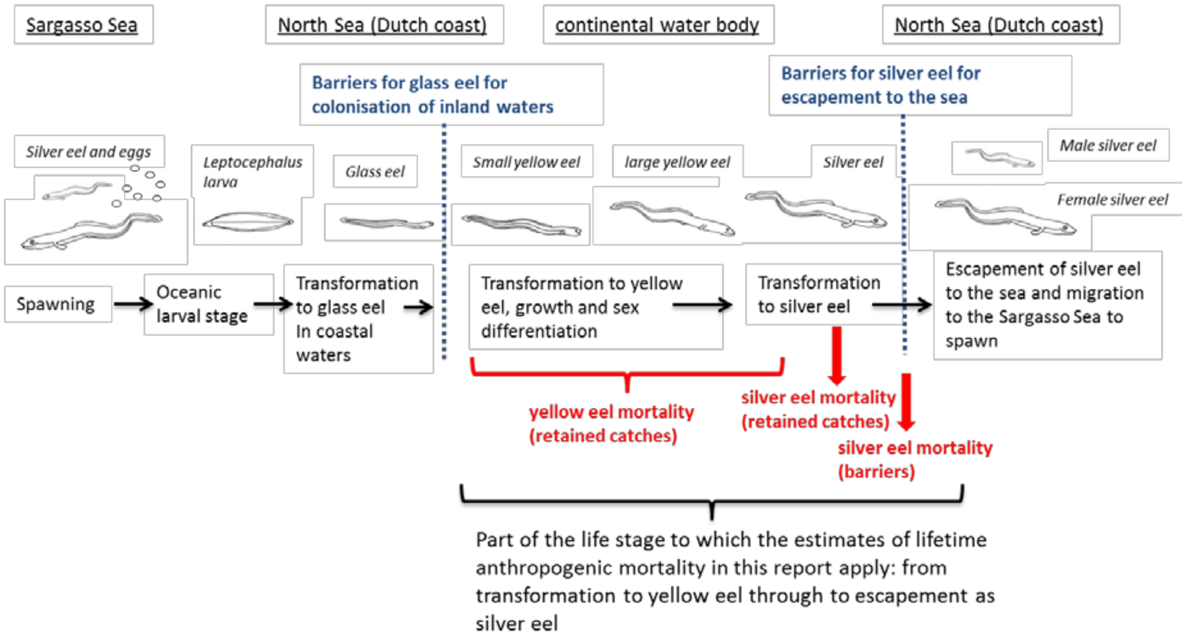

Figure 1.1 The life cycle of a European eel, with the part of the life cycle to which the Dutch Eel Management Plan (EMP) applies and for which 'Lifetime Anthropogenic Mortality' (LAM) rate estimates are made in this report.

Yellow eel mortality rates were estimated as the proportion of the estimated retained yellow eel catches (by both commercial and recreational fisheries) out of the estimated total current standing stock of yellow eels with body lengths above 30 cm. Thus, both types of fisheries were assumed to be fully selective for eels above 30 cm in length, and entirely non-selective for eels smaller than 30 cm. Yellow eel retained catches were estimated by splitting the total reported retained catches by the commercial fisheries into yellow eel and silver eel, using data from biological market sampling of these catches. Retained catches from recreational fisheries were assumed to consist entirely of yellow eel catches as the digestive tract of silver eel degenerates and feeding ceases. The harvested proportion of the yellow eel stock was estimated as the retained catch divided by the sum of the estimated standing stock and the retained catch. Given the estimated current harvested proportion (which can be transformed into an estimate of fishing mortality rate), a %SPR was estimated using the yellow eel demographic model. This estimate represents the %SPR that a cohort of eels would be expected to produce if they would be exposed throughout their lifetime (from glass eel to silver eel) to the estimated current fishing mortality rate.

Silver eel mortality rates were estimated as the proportion of the retained silver eel catches by commercial fisheries out of the estimated total current production of silver eels, and an additional mortality rate by barriers (pumping stations, hydropower plants, sluices, etc.) during silver eel migration. Silver eel retained catches were estimated by splitting the total reported retained catches by commercial fisheries into yellow eel and silver eel, using data from biological market sampling of these catches. The mortality rates induced by migration barriers were estimated using a model in which the starting positions of silver eels were split into three hierarchies of water bodies: 1st hierarchy: silver eels that start from 'polder' ('drainage ditches' below sea level) water bodies; 2nd hierarchy: silver eels that start from larger inland regionally managed water bodies with no open connection to the sea (referred to as 'boezem'), and; 3rd hierarchy: silver eels that start from large nationally managed water bodies such as the major lakes and main rivers. Mortality rates of barriers were estimated for each hierarchy. Mortality rates induced by barriers in polder water bodies were estimated by means of a meta-analysis of results of studies on a large number of pumping stations. Mortality rates induced by barriers in boezem water bodies and large nationally managed water bodies were estimated from a recent analysis of the top prioritised migration barriers for eel (Winter et al. 2013a), based on current knowledge from telemetry experiments and detailed studies into mortalities induced by these barriers. Barriers were assumed never to be in sequence within a hierarchy, but a proportion of silver eels was assumed to be transferred from a lower to a higher hierarchy of water body e.g. from the 1st to the 2nd hierarchy) implying that barrier mortalities could apply sequentially in this manner. An exception was made for silver eels that were estimated to be produced in water bodies upstream of the main hydropower plants in the main rivers, for which separate mortality rates were estimated.

As explained above, estimates of the standing stock biomass of silver and yellow eel are necessary to 1) for both silver eel and yellow eel: estimate fishing mortality from retained catches and 2) for silver eel only: split the starting positions of silver eels into the three hierarchies of water bodies (“polder”, “boezem” and “nationally managed”) as explained above. To estimate the standing stock biomass, a spatially explicit approach was taken to unambiguously define the delineations and wetted areas of water bodies included in the assessment. Estimates of absolute stock size were made in two different ways:

1) Static stock survey: Stock estimates were made on the basis of data from electric dipping nets, by scaling data on density (eel biomass per length class per swept area) to total wetted areas of water bodies.
2) For the two main lakes (IJsselmeer and Markermeer) direct estimates of fishing mortality rates were made by fitting the yellow eel demographic model to a long term stock survey data set (electrotrawl survey) of catches per unit of effort per length class. The estimated fishing mortality rates were used to obtain estimates of the total standing stock of eel in these lakes, by multiplying the reported retained yellow eel catches with the inverse of the estimated harvested proportion. The estimates of fishing mortalities were also used for lakes Veluwerandmeren and Grevelingenmeer, since no electrotrawl or electric dipping net data were available for these lakes.

The silver eel production per water body was estimated by splitting the total standing stock into length classes (using the electric dipping net data) and multiplying this with estimates of the proportion of silver eels out of all eels per length class (a ‘maturity ogive’). The maturity ogive was estimated using biological market sampling data. For the lakes for which no electric dipping net data were available (and estimates were based on direct estimates of fishing mortalities), an estimate of 42% silver eel out of the total standing stock biomass was used based on the market sampling data of Lake IJsselmeer and Markermeer and the biological keys.

The main data sets which were used for the stock assessment were:

1) **Reported landings** by commercial fishers (by Fish Stock board; ‘Visstandbeheerscommissie’(VBC)); since 2010 these landings are provided by the Ministry of EZ and are stored at IMARES in the Visstat database of fisheries statistics.
2) **Biological data from market sampling of landings** by commercial fishers. During visits to fishers a representative sample of (usually) 150-200 eels was selected from the landings, and lengths of individual eels were measured in order to estimate length-frequency distributions of the landings. Furthermore, a number of eels were selected from each sample for dissection and the estimation of maturity-at-length, weight-at-length and sex-ratio-at-length. Sex-specific growth curves have been estimated from age readings of 300 eel otoliths from different areas in the Netherlands, including the large lakes and main rivers. The biological keys are presented in Chapter 2 and are used in the demographic model (Chapter 3) and in the static spatial model (Chapter 4).
3) **Surveys** of fish stocks in the **regionally managed water bodies**. Eel sampling within the Water Framework Directive (WFD) waters was done following an EU certified protocol. In the assessments presented here, we used only data from electrofishing with electric dipping nets. These data could be used to estimate densities of standing stock on a wetted area basis most straightforwardly. Sampled water bodies are representative for water types defined within the Netherlands based on WFD regulation. Data collection is managed by regional water boards and unfortunately, at present, the WFD fish monitoring data are not stored in a central database. Electric dipping net data for recent years were obtained from ATKB and several water boards. A total of 3583 samples by electric dipping net were available between 2006 and 2013, covering most of the combination of water boards and water body types. However, data from some regional water boards were missing in the analyses.

4) **Surveys** of fish stocks in the **nationally managed water bodies**. The shores of the main rivers (Meuse, Rhine and their downstream counterparts) were sampled yearly using an electric dipping net.
5) **All water bodies which are included in the Dutch Water Framework Directive (WFD)** have been included In the assessments presented in this report, with the exception of coastal water bodies. The WFD (2000/60/EC (WFD)) has been established by the European Union as a legal framework for the protection and restoration of the aquatic environment across Europe by 2015. A total of 3402 water bodies form the main basis for the stock assessment. Drainage ditches are underrepresented in the set WFD water bodies, and were added separately to the spatial model.

1.3 Flow diagram of the stock assessment methodology and structure of this report

As explained in paragraph 1.2, the stock assessment methodology consists of a number of steps before the final overall assessment of %SPR can be made for the whole of the Netherlands. The steps leading up to the final overall assessment are:
1) The development of a **demographic model for yellow eel** (**Chapter 3**), for the estimation of the best possible spawner production per glass eel, and the reduction in spawner production for a certain level of yellow eel mortality (%SPR).
2) **Estimation of standing stock biomass** based on fitting the demographic model to stock surveys for lakes IJsselmeer and Markermeer (**Chapter 3**) and by using a static spatial model using survey data (**Chapter 4**) is reported in **Chapter 5**. **Chapter 4** starts with a description of the water bodies and their main attributes (such as total wetted area) which are included in the assessment. For the larger, mostly nationally managed water bodies such as the main rivers and for the majority of smaller, mostly regionally managed, water bodies, data from surveys using electric dipping nets were available. Fishing operations using electric dipping nets usually take place only close (~1.5m) to shores of water bodies. A separate estimate is therefore needed for the standing stock in the wetted area further than 1.5 meters from the shore/bank, which is estimated in different scenarios as a proportion of the density of eel “within-shore” (<1.5 meters from the shore/bank). In addition, two fishing mortality scenarios were used for the estimates of the large lakes (**Chapter 3**). Besides different scenarios three different periods are used for which a stock assessment is done. Estimates of the standing stock biomass of yellow eel and silver eel, which are necessary for the estimation of mortality rates are given in **Chapter 5**.
3) Estimation of mortality in the silver eel stage due to barriers (**Chapter 6**).

The results from Chapters 3, 4, 5 and 6 are subsequently used for the estimation of the key stock indicators for the whole of the Netherlands (**Chapter 7**).

The evaluation of the Dutch EMP is presented in Chapter 8, where the stock indicators are presented in the modified precautionary diagram as developed by ICES. The report concludes with a general discussion and recommendations for improvements to the stock assessment methodology (**Chapter 9**).

The flow diagram below (Figure 1.2) gives a broad overview of the key step in the stock assessment methodology, with reference to the chapters and key paragraphs therein.

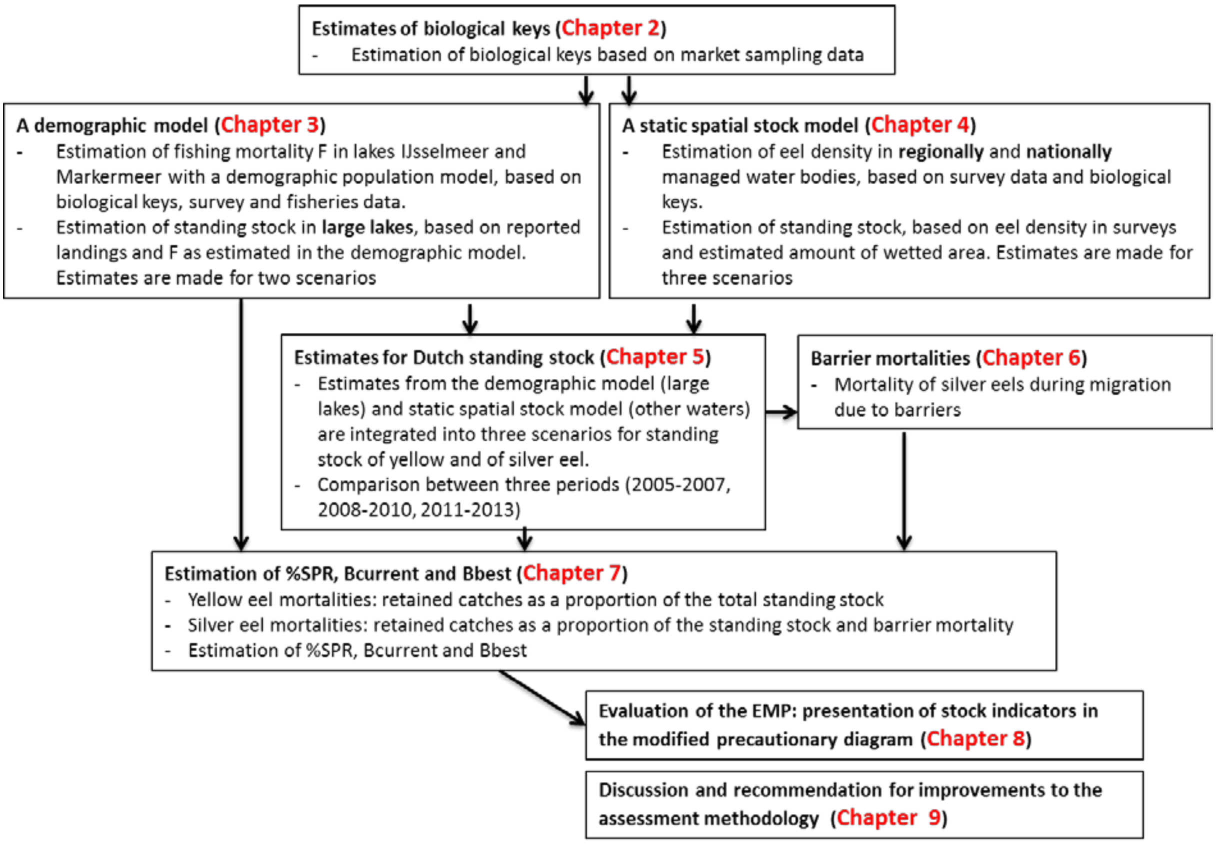

Figure 1.2 A flow diagram representing the key steps in the stock assessment methodology, and the structure of this report (with reference to chapters and key paragraphs therein).

2. Estimates of biological keys

Similar to the parameter estimates presented in Bierman et al. (2012), samples from retained commercial catches were analysed to provide biological information on the eel population in the Netherlands. The samples were taken from commercial catches (i.e., 'market samples') from different regions in the Netherlands (Van Keeken et al. 2010, 2011). The number of market samples per region was taken proportionally to the catch size of the region. Analyses were done on all data disregarding region, thereby using the largest possible data set, resulting in estimates representative for a national eel population (Bierman et al. 2012). Data collected from 2009 to 2013 were used in the analyses, resulting in a total of 9427 individuals. For all these eels sex, length, weight and maturity was assessed. Of 300 individuals, sampled in 2009-2012, the otoliths were analysed to assess inter annual growth increments. Here, an update of the biological parameters is given of those presented in Bierman et al. (2012) as currently more data are available. The biological keys are used in the assessment in the static spatial model to convert lengths to biomass and yellow/silver eel (Chapter 4) and in the demographic model (Chapter 3) (see *Figure 2.1*).

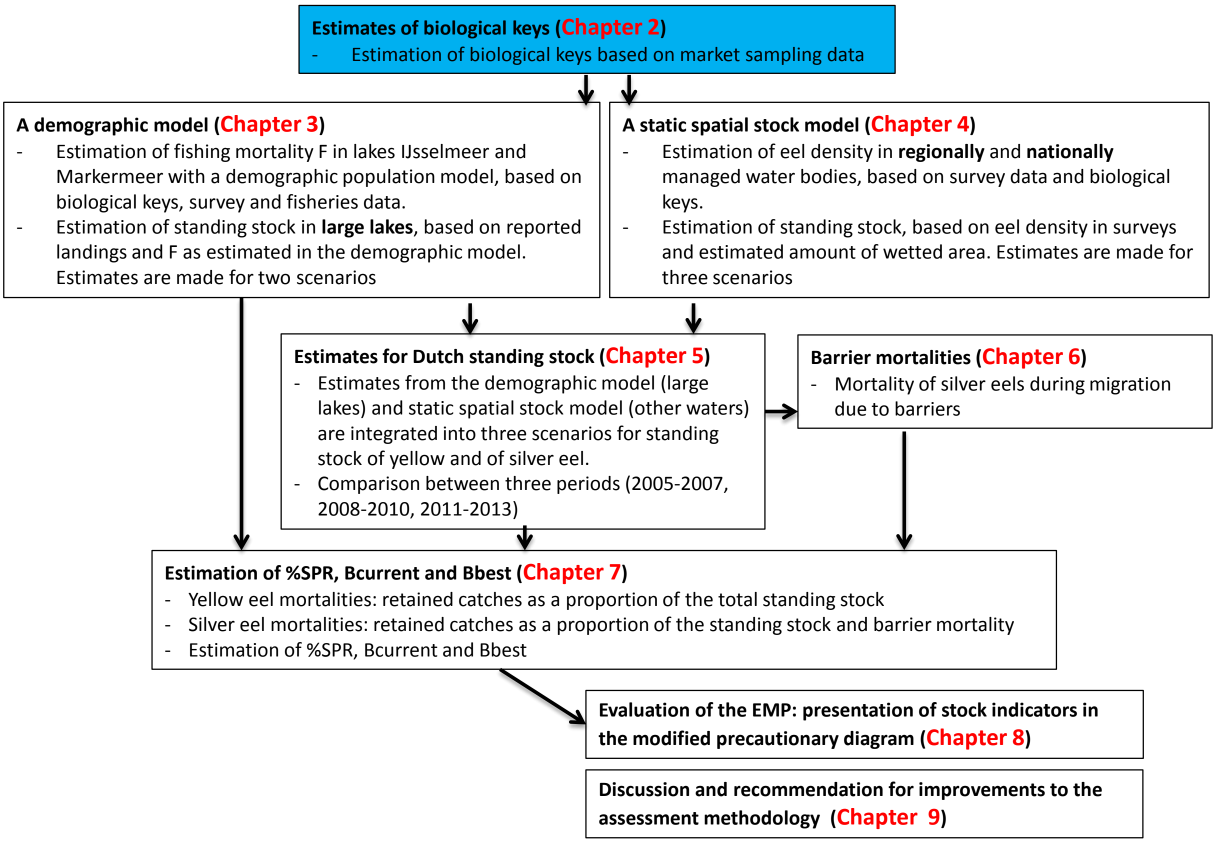

Figure 2.1 Flow chart of the assessment procedure.

2.1 Sex ratio at length

The processes determining sex in eels are not well understood. Sex differentiation in eels is thought to be not, or only partly, genetically determined. Instead, environmental characteristics are thought to play an important role. Densities, either of recruits or adults, are likely candidates, with high densities leading to more males (Roncarati et al., 1997; Davey and Jellyman, 2005; Huertas and Cerda, 2006; Han and Tzeng, 2006; Bark et al., 2007). Sex-ratios in catchments can change over time (e.g. Laffaille et al., 2006) and can differ markedly between local eel populations in different (parts of) water bodies (e.g. Oliveira et al., 2001; Bark et al., 2007). The sex ratio for the size class 30-35cm of lake IJsselmeer and Lake Markermeer is given in *Table 2.1*, illustrating a decrease in the proportion of males in recent years, with a mean value of 59% for Lake IJsselmeer (period 2004-2013), and a mean value of 41% for Lake Markermeer (period 2009-2013).

*Table 2.1 Sex ratio of eel from the market samples for length class 30-35cm for lake IJsselmeer and Lake Markermeer separately for 2009-2013. *Data from 2004 to 2008 were taken from Bierman et al. (2012) and are for Lake IJsselmeer and Markermeer combined.*

Year	IJsselmeer			Markermeer		
	Females (n)	**Males (n)**	**% Male**	**Females (n)**	**Males (n)**	**% Male**
2004*	10	48	83			
2005*	15	66	82			
2006*	10	29	74			
2007*	34	27	44			
2008*	31	41	57			
2009	18	19	51	32	18	36
2010	26	53	67	22	23	51
2011	19	22	54	9	14	61
2012	25	16	39	15	7	32
2013	16	11	41	9	3	25

The sex ratio at length was estimated based on the samples from the catches from 2009 until 2013. In Bierman et al. (2012) only eel from 2011 were used, making the current relationship based upon more data. The sex ratio as function of length was based on the data from all regions combined to increase sample size (Figure 2.2). Sex ratio was assessed only for lengths larger than 20 cm, because determination of the sex ratio is problematic below this length. In addition, only samples from catches from 2011 onwards contained individuals smaller than the legal landing size of 28 cm. The catches prior to 2011 were taken from sorted catches and therefore include only eel of 28cm and larger. Catches from 2011 onwards were sampled including undersized individuals, before sorting of the catch and the release of undersized individuals. Of all the market samples from 2009-2013 4810 were females, 1240 were males and of 3377 individuals sex could not be determined. Only length classes (1 cm classes) with 5 or more individuals were taken into account, resulting in a total of 6027 individuals used.

Per 1 cm length class the percentage of females was determined (dots in Figure 2.2). Subsequently, the length-sex ratio relationship was estimated for the length classes between 200 mm and 500 mm by linear regression ($P < 0.0001$). From 500 mm onwards the percentage females was set at 100.
The percentage females (%F) is dependent on length (L, in mm) by:

a) $200 < L < 500$ $\%F = -0.56 + 0.003*L$
b) $L >= 500$ $\%F = 100$

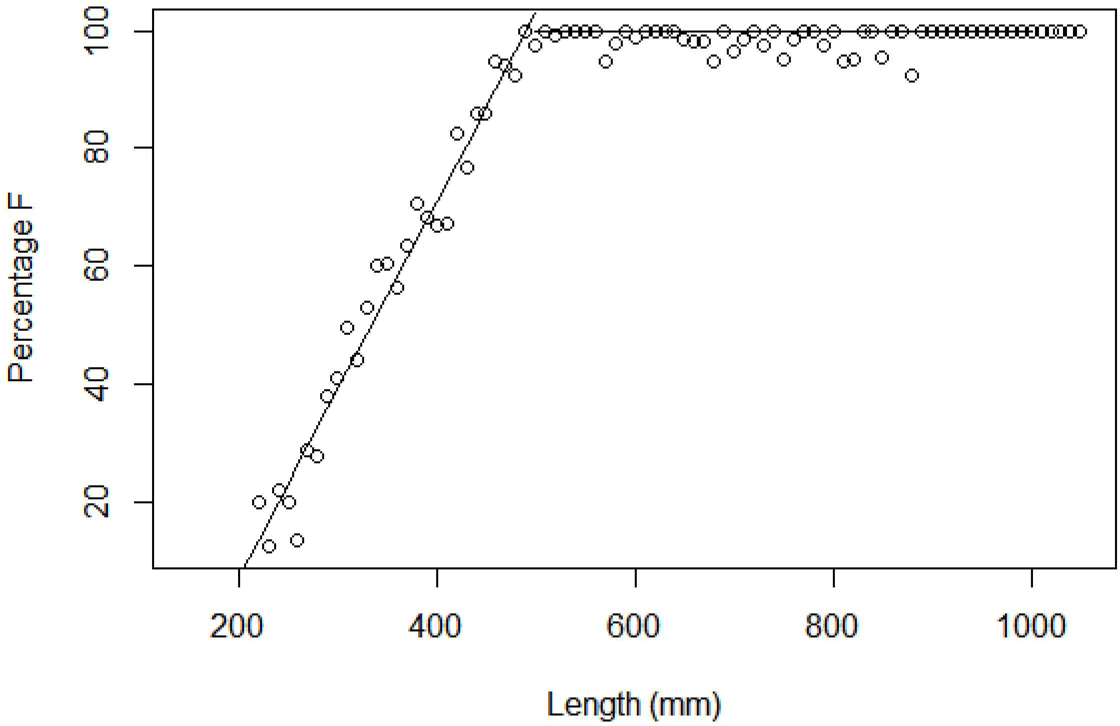

Figure 2.2 Percentage females based upon all samples from the market catches 2009-2013 (circles, in 1 cm classes). The fit (solid line) is linear for lengths between 200 to 500 mm (R2 = 0.9765). Individuals of 500 mm and above are considered female.

The sex ratio at length was used in the static spatial model in order to split the survey data into males and females. Based on the sex ratio the other biological keys were then used to assess stock biomass. Both the data on which the sex ratio at length was based as the survey data used in the spatial static model are from recent years. For the demographic model, which encompasses a much longer time series this sex ratio at length was not used because the sex ratio has changed over time and data for a sex ratio at length are not available. Hence for the demographic model a coarse assumption is made on the change in sex ratio with a decrease in the fraction males (as indicated in *Table 2.1*).

2.2 Maturation at length

Because of the closure of the eel fishery in the Netherlands during the silver eel migration season since 2009 the sampling of the commercial catches could underestimate the proportion silver eel in the Dutch stock (and thus the percentage maturity). However, taking catches from the migration season could overestimate the proportion silver eel as these have likely a higher catchability due to increased mobility. In addition, at downstream locations the silver eel in the catch may originate from upstream locations, which could cause an overestimate of the proportion silver eel downstream and an underestimate of the proportion silver eel upstream. Factors such as these need to be considered when interpreting the proportion silver eel.

The maturity (yellow/silver eel) at length was fitted for both sexes separately. The percentage of silver eel out of the total eel catch was fitted with a logistic function (*Figure 2.3*, *Table 2.2*). In Bierman et al. (2012) only eel from 2011 were used, making the current relationship based upon more data.

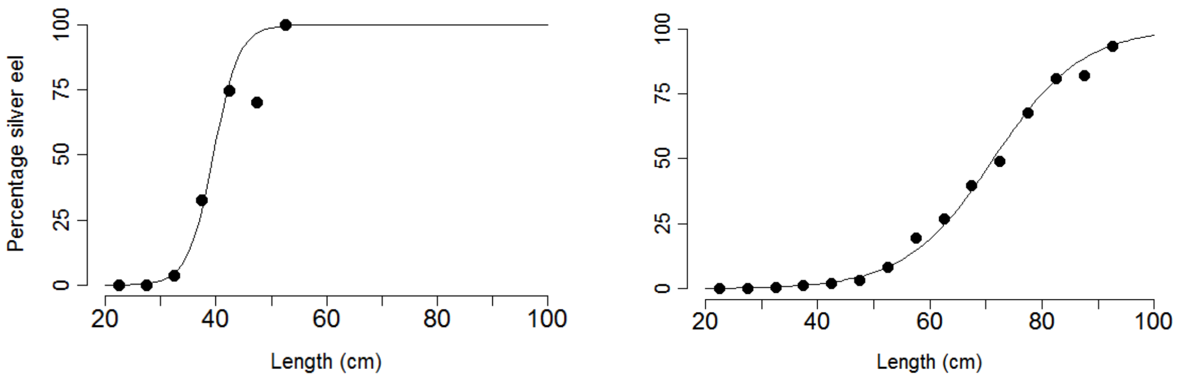

Figure 2.3 Observed (circles) and predicted (lines) proportions of silver eel out of the total number of eels in the retained catches, per length class (5 cm classes). Left: males; Right: females.

Table 2.2 Estimated fractions of silver eel per length class (5 cm intervals). The fraction silver eel is estimated using a logistic model which has been fitted to observed proportions of silver eels in retained catches of commercial fishers (see Figure 2.3).

Sex	**Length class (5 cm intervals)**																
	10 <15	**15 <20**	**20 <25**	**25 <30**	**30 <35**	**35 <40**	**40 <45**	**45 <50**	**50 <55**	**55 <60**	**60 <65**	**65 <70**	**70 <75**	**75 <80**	**80 <85**	**85 <90**	**=>90**
Males	0	0	0	0.005	0.04	0.29	0.78	0.97	-	-	-	-	-	-	-	-	
Females	0	0	0	0	0	0	0	0	0.08	0.15	0.24	0.38	0.53	0.68	0.80	0.89	0.95

2.3 Weight at length

The following length-weight relationship is used to estimate eel biomass given numbers-at-length based on the market samples (2009-2013):

$$\textbf{Weight} = \exp(-14.15 + 3.156 * \log_e(L))$$

With weight in grams and length (L) in millimetres. The data points and the fitted curve are presented in *Figure 2.4*. In Bierman et al. (2012) only eel from 2010 were used, making the current relationship based upon more data.

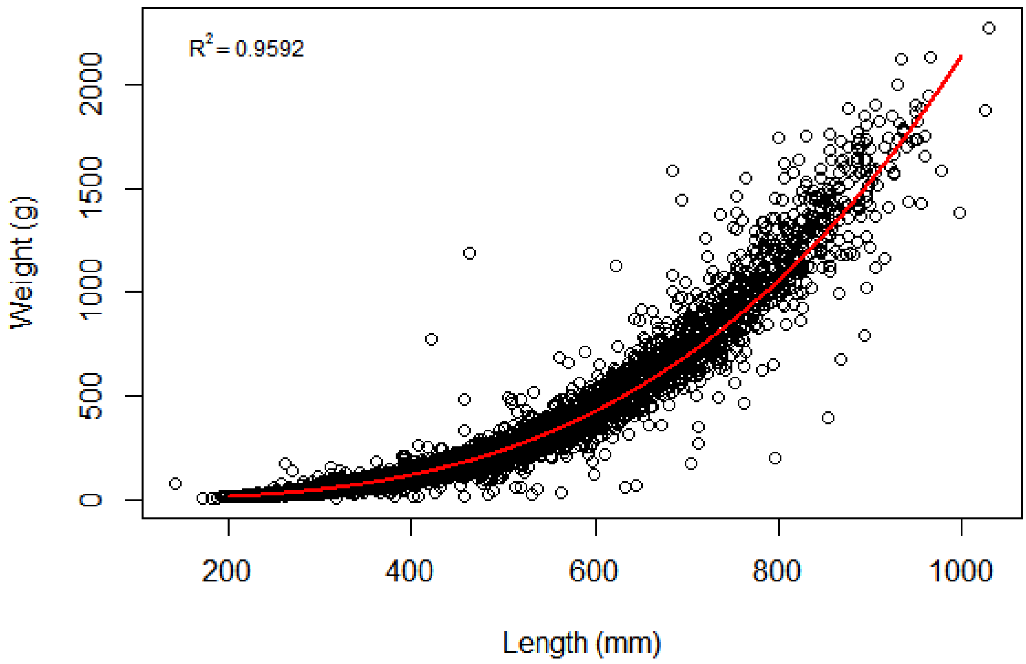

Figure 2.4 Length-weight relationship for eel based on the available data (red line) and the data points from the market sampling (2009-2013).

2.4 Growth rate

Growth rates are analysed for the sexes separately. Increments were based on otolith reading of back-calculated length from eels collected in 2009-2012 (*Figure 2.5*). In Bierman et al. (2012) otolith readings of 200 eels were available, now readings of 300 individuals were available. Individual growth curves were constructed using the relative distances between annual growth rings and scaling these to the total length of the eel (van Keeken et al., 2011). For the determination of growth curves and ages, the protocols set by the ICES workshop in Age Reading of European and American Eel 2009 (WKAREA) were used. It was assumed that glass eel enter the freshwater system at a length of 7.5 cm. The sex specific growth curve is defined as the cumulative average increment at age. This means that the average increase in length per age class is added to the average increase in the age classes before that. This is different from a curve based on the average length-at-age, where the average is simply calculated per age (without taking prior years into account). Using average length-at-age might be biased for several reasons, among which size-selectivity of the gear used for the commercial catches. Using the cumulative growth increment results in a smoother growth curve and prevents ‘shrinking’ of individuals at older ages which does occur when using the average length-at-age in the demographic model (*Figure 2.5*). Because the cumulative growth increment is used the growth curve can be higher than the observed growth patterns of especially slow growing, old, individuals (see for example Figure 2.5 left panel).

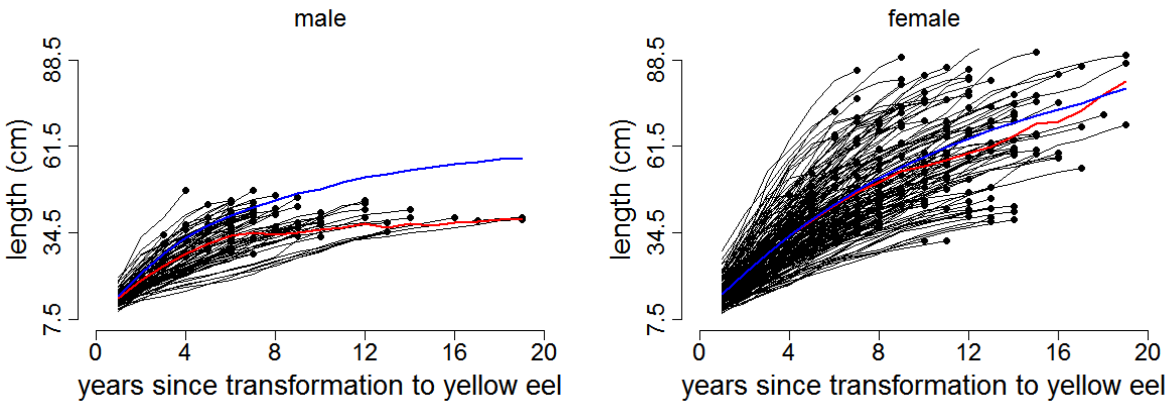

Figure 2.5 Growth curves of individuals (black lines), estimated by allocating the length of the eel (minus 7.5 cm of length assumed for glass eel entering the freshwater system) to ages in proportion to the relative measured width of the year-rings in the otoliths. The estimated cumulative growth curve is given in blue (used in the model). The average length-at-age curve is given in red. Curves are based on 91 males and 209 females.

The estimated growth curves are used in the demographic model as annual transition rates between length classes.

Compared to the estimate presented in Bierman et al. (2012) the growth rate of males is somewhat lower. This reduced male growth rate has an effect on the fishing mortality estimate of the demographic model. Growth influences maturation, with a decrease in growth rate, fish become less large per age class, and thus maturation occurs at higher ages (since maturation is dependent on length, not age). Hence individuals are present in the yellow eel population for a longer period of time and longer prone to fishing mortality. In the demographic model reduced growth thus results in a higher estimate of fishing mortality.

2.5 Selectivity of the fisheries at length

In order to interpret length-frequency distributions of retained catches, and to predict the impact of fisheries mortality on the spawner-to-recruit ratio, it is necessary to define the selectivity of the fisheries at length. Most of the commercial fisheries on eel takes place using fyke nets, with a legal minimum landing size of 28 cm. We assume that most catches of eel below 30 cm are returned, and that there is no mortality associated with catch-release. Furthermore, we assume that the fishery is fully selective at lengths above 30 cm. The selectivity-at-length of the fishery as assumed in the eel stock model is given in *Table 2.3*.

Table 2.3 Assumed selectivity of the fisheries at length.

Length class (5 cm intervals)															
10 15	**15 20**	**20 25**	**25 30**	**30 35**	**35 40**	**40 45**	**45 50**	**50 55**	**55 60**	**60 65**	**65 70**	**70 75**	**75 80**	**80 85**	**>85**
0	0	0	0.5	1	1	1	1	1	1	1	1	1	1	1	1

2.6 Natural Mortality

For natural mortality an estimate is used of M=0.138 (per year) for all ages and lengths, as in Dekker (2000), van der Meer (2010) and Bierman et al. (2012).

2.7 Discussion

Various (potential) shortcomings of the available data may influence the outcome of the spatial and demographic model. The estimates of the biological keys is used as input in both demographic model as well as the static spatial model.

Because of the pronounced differences between the sexes in length-at-age and maturity-at-length, detailed long-term information on sex-ratios is necessary for the interpretation of length-frequency distributions. However, such trends are not available. Obtaining unbiased estimates of sex-ratios is difficult given the differences in length at maturation and age at maturation between the sexes, and practical difficulties and possible biases in determining the sex.

Eels leave the population after maturation, which in a stock assessment is an event with a similar net result on the standing stock as death. The maturation-at-length key is based on data collected in the commercial fisheries (the market sampling). This presents a problem for the male data because the commercial fisheries become selective for individuals with body lengths from approximately 30 cm onwards, which coincides with the lengths above which males mature and leave the population. Both the male maturation-at-length key and the sex ratio estimate may be influenced by this potential underrepresentation of males in the market sampling. If so, this will have led to biased estimates of fishing mortalities.

Given the strong decrease in standing stock densities and recruitment it is unlikely that vital rates such as natural mortality and immigration or emigration rates have remained constant. The eel stock in the Netherlands is spatially structured, and there is an unknown degree of immigration and emigration between linked water bodies. In a stock assessment, immigration and emigration are events which are equivalent to recruitment and death respectively. Ignoring these rates when interpreting length-frequency distributions may lead to severely biased estimates, whereas information on spatial movements of eels is lacking to build more complex spatially explicit models.

3. A demographic model for yellow eel

The demographic population model as presented by Bierman et al. (2012) was used to estimate fishing mortality rates for the two largest lakes, Lake IJsselmeer and Lake Markermeer.
Different scenarios were investigated, in order to take uncertainty of the estimated parameters into account. With these estimated fishing mortality rates an estimate of the standing stock in the lakes is made in Chapter 3.2.

The results of this chapter feed into the estimates of the Dutch stock as well as the estimation of %SPR (*Figure 3.1*).

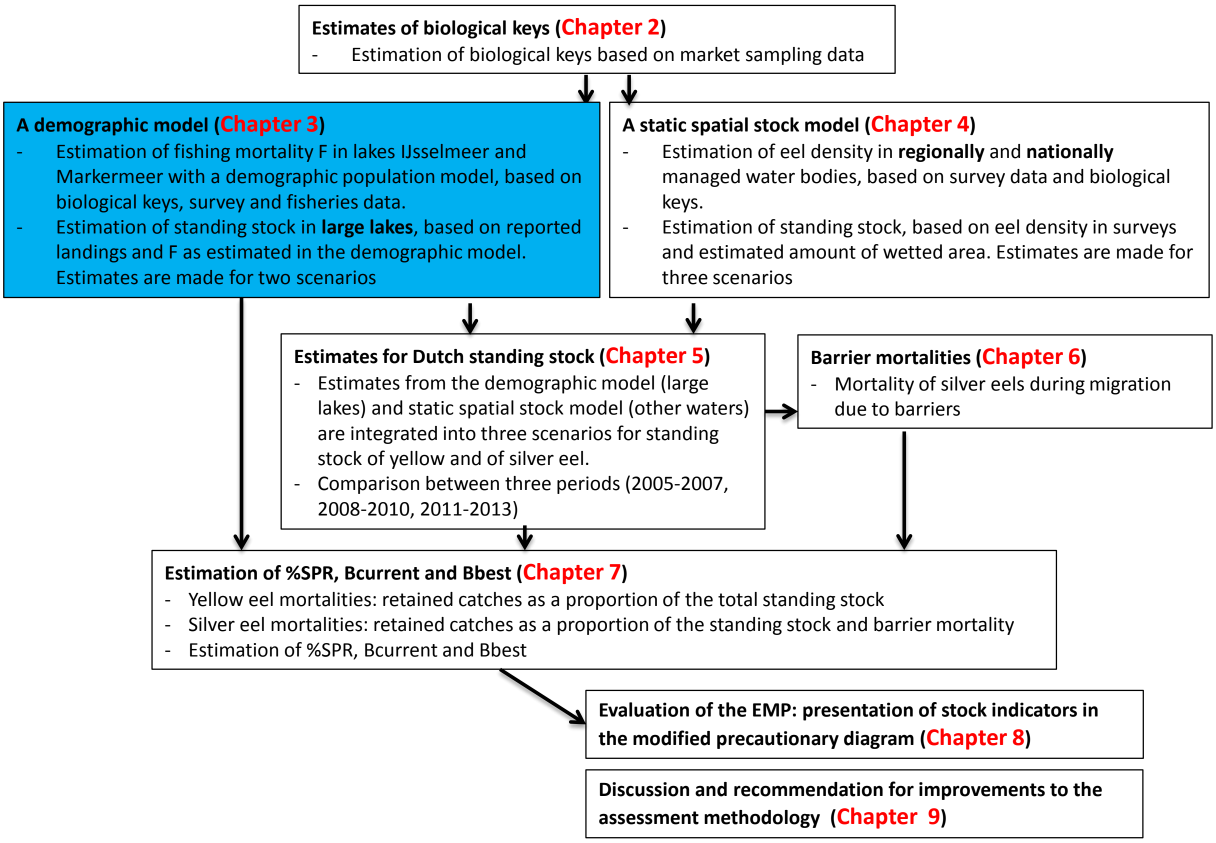

Figure 3.1 Flow chart of the assessment procedure

3.1 Demographic model

The demographic model follows eel cohorts that enter the model as glass eel on an annual basis. The model is based on the assumption that the lake is a closed system (Oeberst and Fladung, 2012; Ciccotti et al., 2012). Glass eel entering the lake are assumed not to migrate further and silver eel are assumed to be produced locally. This is a simplification of the situation in the Netherlands, but assumptions otherwise are just as arbitrary. New glass eel enter the model based on the glass eel index, as recorded each spring at Den Oever (*Figure 3.2*). Each year individuals grow, mature and die based on length- and sex- specific biological parameters described in Chapter 2. All eel suffer from natural mortality and larger eel additionally from a length-based fishing mortality (Chapter 2). Eel leave the population when maturing to the silver eel stage. The change in the annual length-frequency distribution and the total number of eel is then a matter of bookkeeping of all cohorts through time.

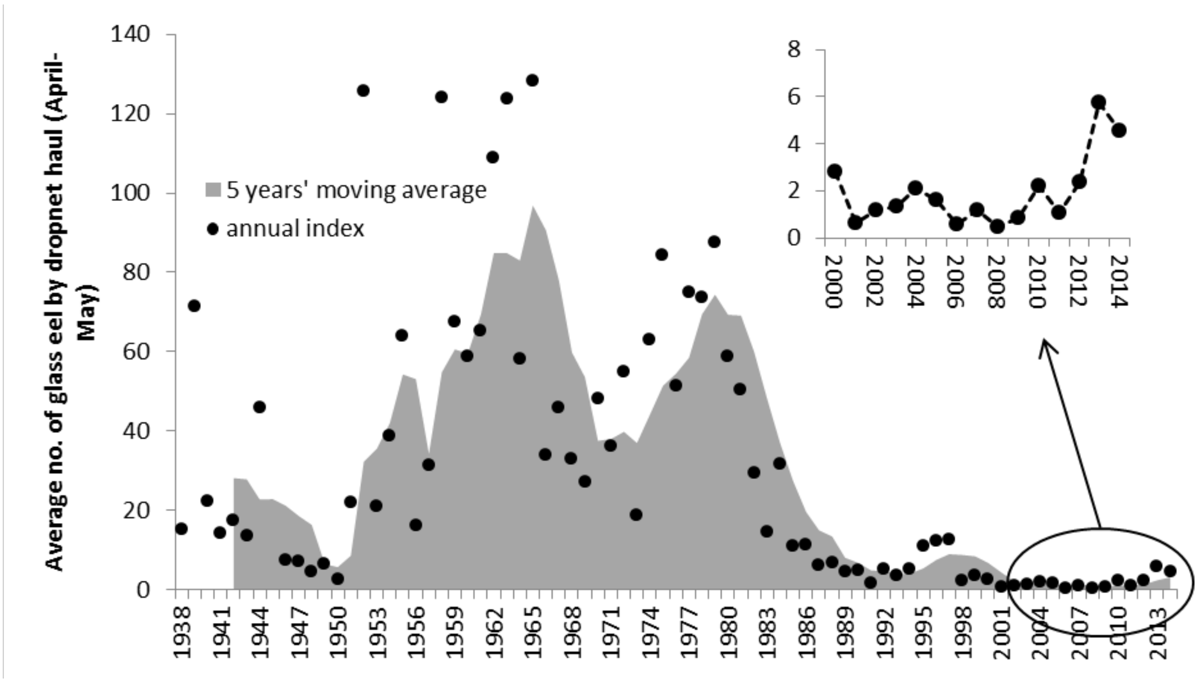

Figure 3.2 Glass eel numbers per haul presented as annual index and as a 5-year moving average, monitored at Den Oever.

Let $N_{a,j,t}$ be the numbers of eels of age *a* (years since transformation to yellow eel), of sex *j* ($j \in \{male, female\}$) in calendar year *t*. Glass eels are assumed to have age *a*=0 and a length of 7.5 cm. For yellow eels (1 year old or more), let *L(a,j)* be the length class (5 cm intervals; starting from 10 cm) that a yellow eels of sex *j* and age *a* falls in: $j \in \{10-15, 15-20, 20-25, \ldots, 100-125\}$. The length class that a yellow reaches at age *a* is a function of the growth curve of sex *j*. The population model is given by:

$$N_{a,j,t} = N_{a-1,j,t-1}\, \mathrm{e}^{\left(-M-Fs_{L(a,j)}\right)} \left(1 - q_{j,L(a,j)}\right)$$

With *M* and *F* parameters for the natural and fisheries-induced mortality respectively, $s_{L(a,j)}$ the selectivity-at-length of the fisheries, and $q_{j,L(a,j)}$ the probability of maturation for eels of sex *j* in length class *L*.

This type of model is often called 'demographic' model, and is used regularly to describe eel populations (e.g. Dekker, 2000; Oeberst and Fladung, 2012; Ciccotti et al., 2012). Here the model is used to estimate the fishing mortality, given the glass eel entering the population and the biological parameters. The estimates are done by fitting the predicted length frequency distribution from the model to the length frequency distribution from the field obtained by surveys. The model is also used to predict the spawner-to-recruit ratio for a given stock and fishing mortality (Chapter 7).

It is important to realise that fishing mortality estimates depend heavily on the biological parameters used in the model. For example, maturation in the model is considered a loss of eel for the system (since silver eels are assumed to migrate to sea), which has a direct consequence on the fishing mortality estimate. An increase in the maturation rate (earlier maturation) will lead to a decrease of the estimated fishing mortality on the stock in the lakes. Thus, a change in maturation rate, but also a change in sex-ratio and in growth rate will affect the migration of silver eel out of the modelled population, and hence the fishing mortality estimate for the modelled population. Uncertainty in the biological parameters increases the uncertainty in the mortality estimate, as was already made clear in Bierman et al. (2012) and as in Bierman et al (2012) different scenarios will be used to deal with the uncertainty.

Varying sex ratio and fishing effort.

For lake IJsselmeer and lake Markermeer fishing mortality was estimated using a change in sex ratio, with a decreasing proportion of males (*Table 3.1*). This is based on the decrease in time in the proportion males as suggested in the data (*Table 2.1*) and literature on density dependent processes governing sex ratios and changes of sex ratios in other catchments (e.g. Roncarati et al. 1997, Davey & Jellyman 2005, Bark et al. 2007).

Table 3.1 The proportion males for different fishing periods with a changing sex ratio.

Fishing Period	Proportion Males
<1990	0.7
1991-2000	0.6
2001-2013	0.5

In addition, the model was run for different periods because of sharp changes in 'potential fishing effort' through time (*Figure 3.3*): (i) the number of fishing permits has decreased over time in a stepwise manner, with three major changes in total number of permits (see Bierman et al. 2012), and (ii) since 2009 fishing is prohibited during the silver eel migration period (three months, September-December), thereby reducing the fishing season by one-third. The reason this is called 'potential fishing effort' is because only the number of permits is known, but not the realized effort because that is not registered. This leads to five periods with potentially distinctly different fishing effort; four time periods based on reduced permits and 1 time period based on shortening of the fishing season (period 1: 1955-1989; period 2: 1990-1999; period 3: 2000-2005; period 4: 2006-2008; period 5: 2009-2013). For each of these fishing periods the fishing mortality is estimated.

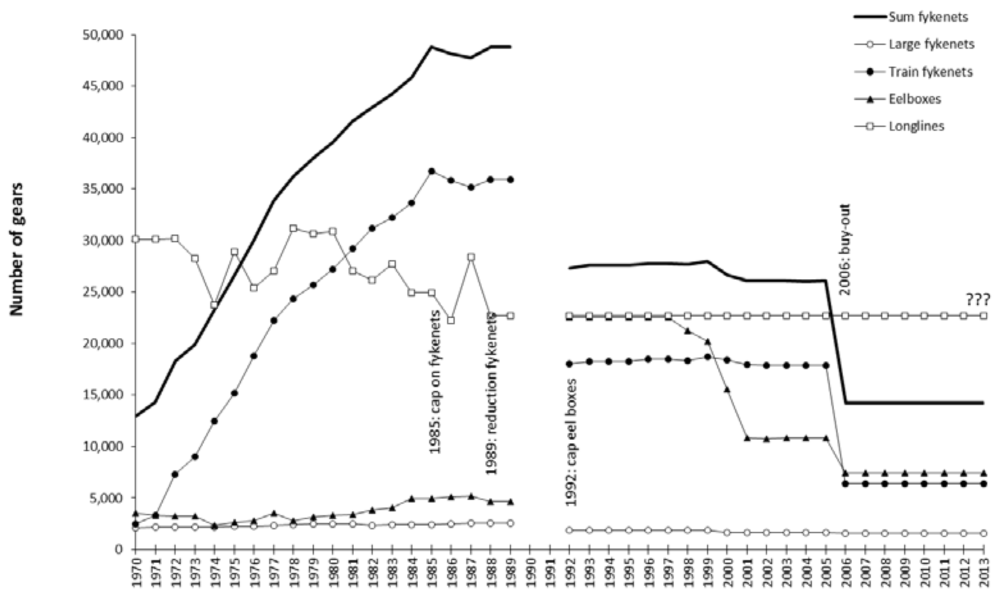

Figure 3.3 Changes over time actual (before 1991) and nominal (after 1991) fishing gears in lake IJsselmeer and Markermeer. An estimate of the number of gears actually used is available for the years 1970-1988 (Dekker 1991). Nominal fish gears are the number of legal, registered fishing gears that could potentially be used, it is however, unclear how many of these nominal gears are actually used in the fishery. Note further that the number of longlines are not registered, only the number of long line licenses, hence the uncertainty ("?") about the number of longlines in the fishery.

In order to estimate the fishing mortality, the model length-frequency distribution is fitted to an observed length-frequency distribution obtained the survey data of Lake IJsselmeer and Lake

Markermeer are used. This survey takes place annually at fixed positions in the lakes since 1989. Fishing mortality estimates were based upon time series of length classes of both the model result and the survey.

Estimating fishing mortality

The estimated fishing mortality and its uncertainty range is given in *Table 3.2*, for both Lake IJsselmeer and Lake Markermeer, for the five periods of fishing mortality. For both lakes the fit of fishing mortality in the most recent fishing period (2009-2013) has the highest variance, and hence has the most uncertainty, especially for Lake IJsselmeer (*Table 3.2*). For the other four fishing periods there is low variance in the estimated mean F; i.e., the estimates are less uncertain. For both lakes the estimated F decreases for more recent periods.

Table 3.2 Model estimated fishing mortality estimates for the two lakes for periods varying fishing efforts, and the 95 and 5 percentiles of the likelihood in brackets indicating variance (after 16000 iterations). The smaller the difference between percentiles, the better the fit.

	IJsselmeer	Markermeer
<1989	1.04 (1.02-1.07)	0.50 (0.48-0.51)
1990-1999	0.81 (0.80-0.83)	0.43 (0.41-0.44)
2000-2005	0.44 (0.42-0.46)	0.46 (0.42-0.50)
2006-2008	0.49 (0.47-0.51)	0.54 (0.50-0.58)
2009-2013	0.15 (0.02-0.30)	0.29 (0.21-0.38)

The model prediction with the estimated F values as in *Table 3.2* for Lake IJsselmeer for each of the size classes and the observed length frequency from the survey data are presented in *Figure 3.4* and *Figure 3.5*. For the smallest size classes the model prediction captures changes in numbers at a coarse level, but the high level of variance in observed numbers is not picked up (*Figure 3.4*). For the size class >55 cm the increase in numbers in recent years is present in the model result. The initial increase in mean length early 2000 is captured by the model, yet the further increase in recent years as observed from the data is not predicted (*Figure 3.5*).

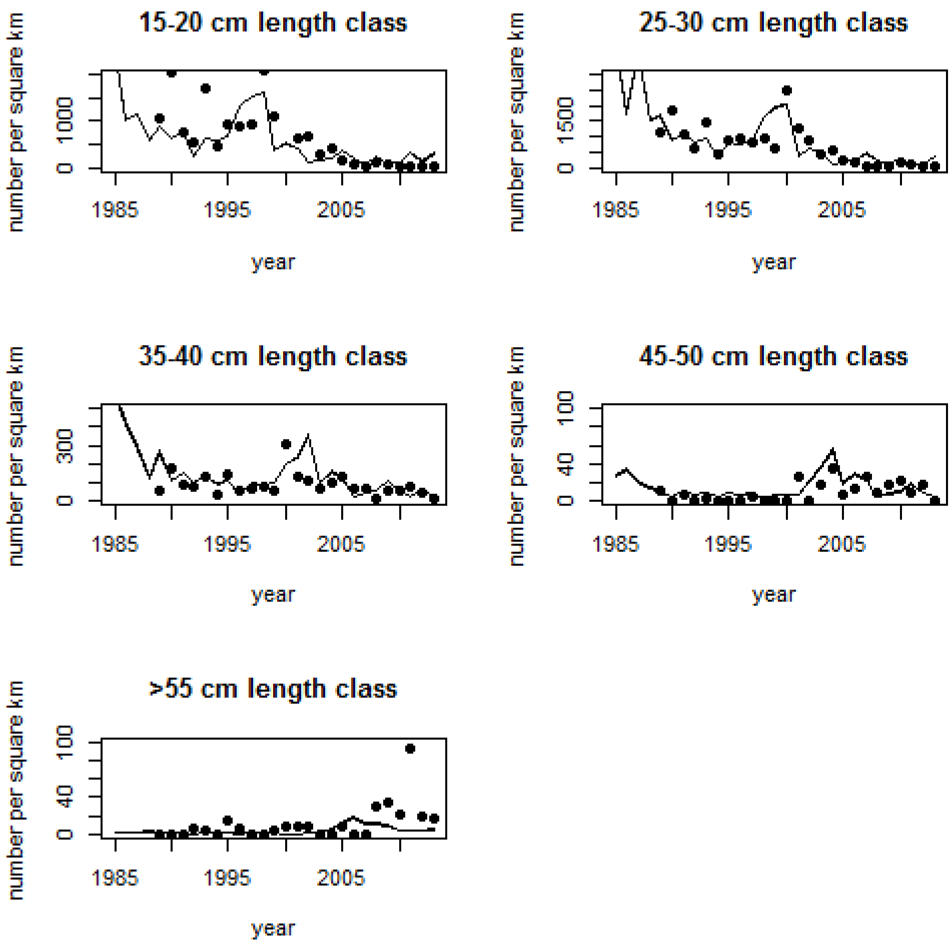

Figure 3.4 Predicted and observed number of individuals per length class. Observed numbers are taken from the Lake IJsselmeer survey. Note that the scale of the y-axis differs between graphs.

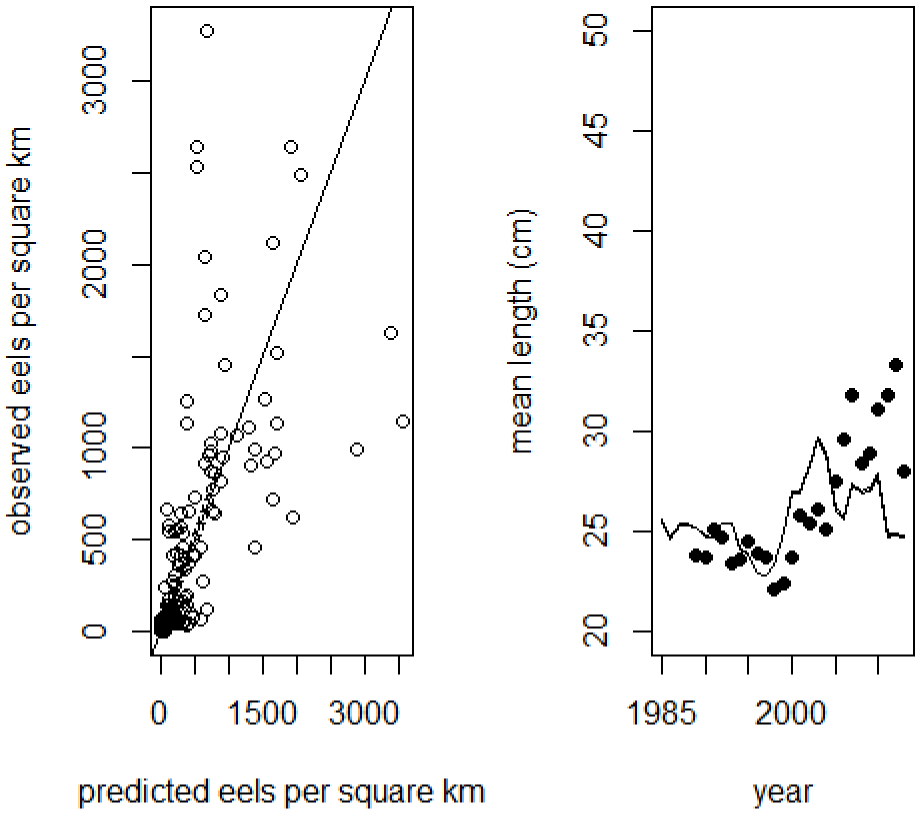

Figure 3.5 Predicted and observed number of individuals per surface area and the annual mean length for Lake IJsselmeer from the model results and survey data. Observed numbers are taken from the Lake IJsselmeer survey.

The model fit and the observed numbers per length class in time for Lake Markermeer is presented in *Figure 3.6*. The observed number of individuals shows less fluctuations than for Lake IJsselmeer and absolute numbers are lower. The recent increase in the mean length as observed in the survey data is based on a small number of individuals per year in the period 2005-2013 (Figure 3.7). This makes the fishing mortality prediction for Lake Markermeer for the last periods uncertain.

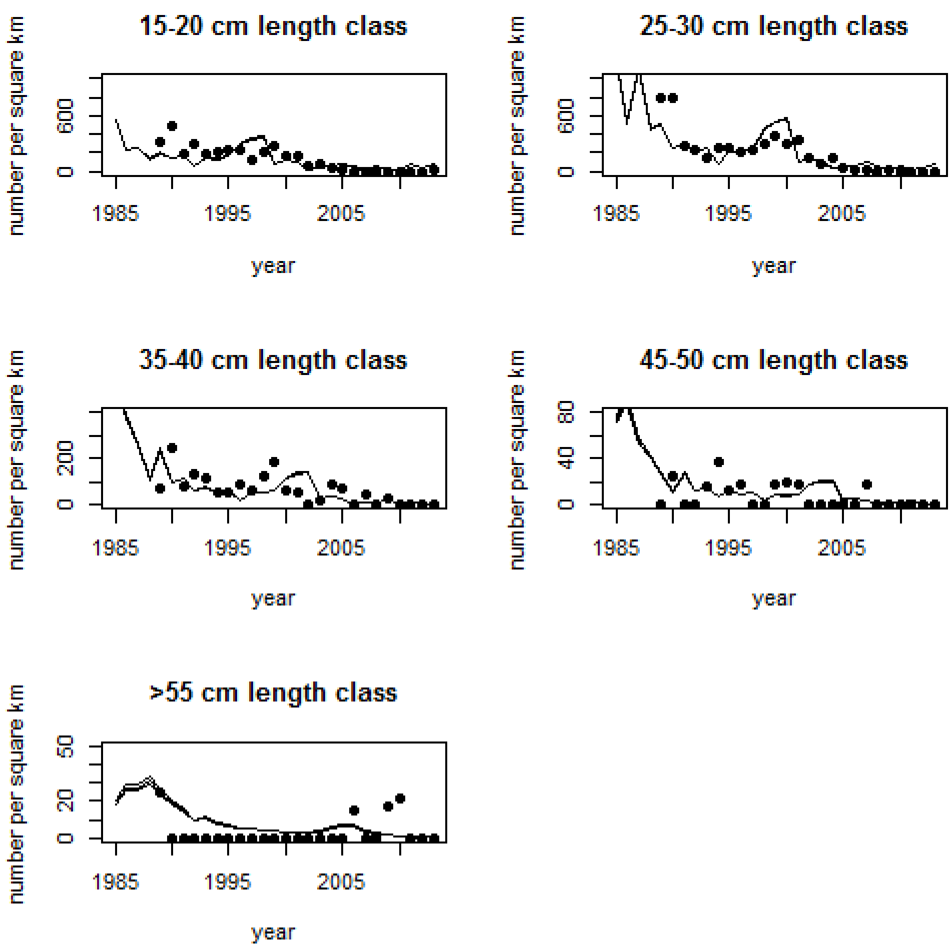

Figure 3.6 Predicted and observed number of individuals per length class for Lake Markermeer. Observed numbers are taken from the Lake Markermeer survey. Note that the scale of the y-axis differs between graphs.

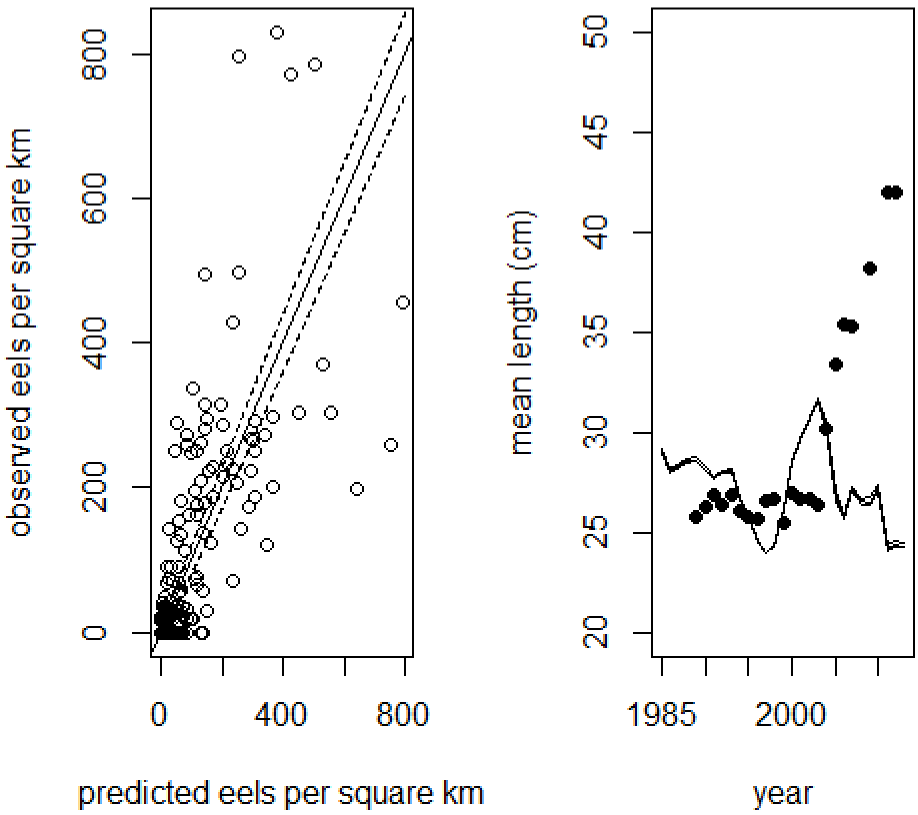

Figure 3.7 Predicted and observed number of individuals per surface area and the annual mean length for Lake Markermeer from the model results and survey data. Observed numbers are taken from the Lake Markermeer survey.

3.2 Standing stock of large lakes

For four major lakes, informative survey data for eel were unavailable. The four major lakes are IJsselmeer, Markermeer, Randmeren and Grevelingenmeer (*Figure 3.8*). The standing stock for these lakes was estimated using data on the commercial landings and fishing mortality as estimated above in the demographic model.

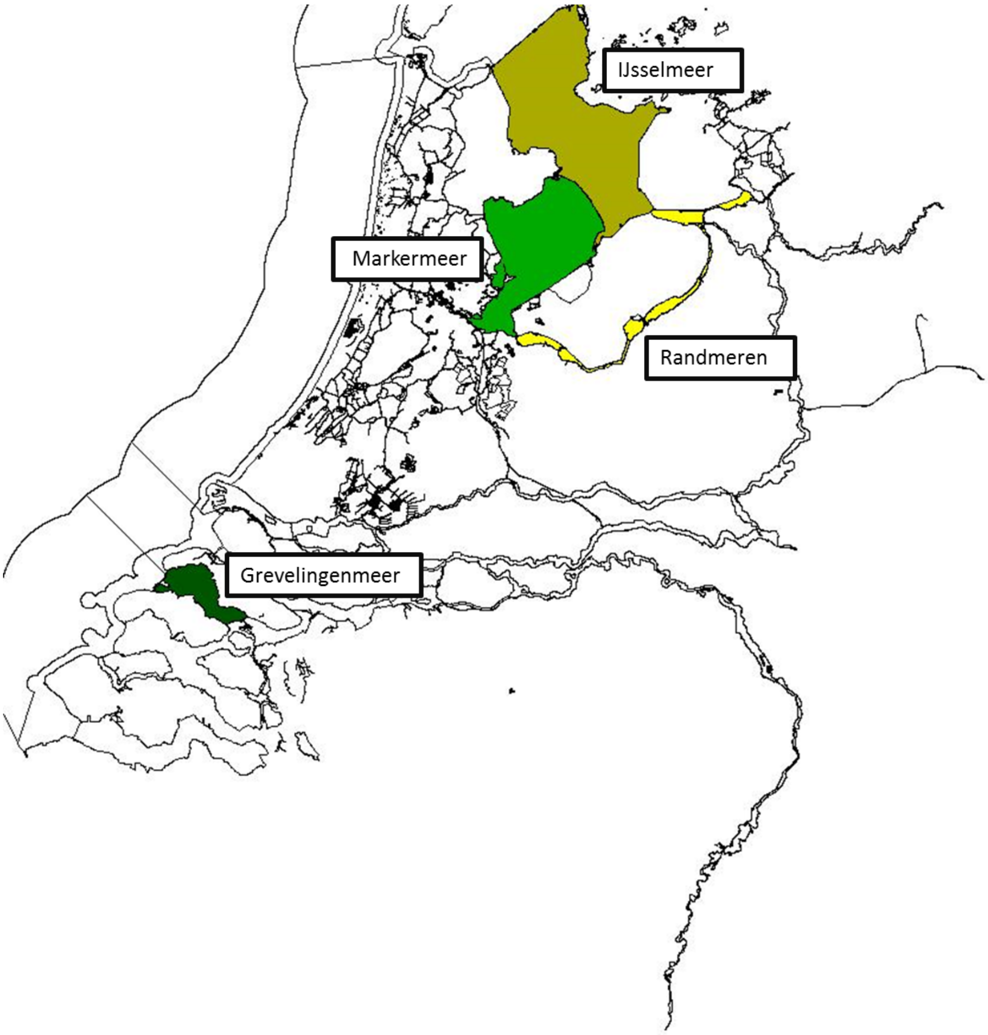

Figure 3.8 The four large Dutch lakes for which standing stock was estimated via landings and estimated fishing mortality.

Fishing mortality: two scenarios

The uncertainty in the demographic model led to two scenarios for fishing mortality being investigated (*Table 3.3*). As in Bierman et al. (2012) Scenario A represents the estimated fishing mortalities from lake IJsselmeer, and scenario B is the average of Markermeer and Lake IJsselmeer.

Table 3.3 The two fishing mortality scenarios used for the estimation of eel biomass for the large lakes based on the demographic model.

	Scenario A	**Scenario B**
2005-2007	0.49	0.515
2008-2010	0.15	0.22
2011-2013	0.15	0.22

Commercial landings

Different data sets of commercial landings data exist in the Netherlands, which do not overlap in time, regions or estimated landing size. The data from the Ministry of Economic affairs (EZ) is available since 2010 and contains data on four large lakes: Lake IJsselmeer and Markermeer combined, Grevelingen and Veluwerandmeren.

Available data were collected from different sources and the result is presented in *Table 3.4*. Catch data from the Product Board ('Coöperatieve Producentenorganisatie Nederlandse Vissersbond – IJsselmeer U.A.', alias "PO") is available for the period 2005 until 2013 and only covers Lake IJsselmeer and Lake Markermeer, but these catches are lower than reported to EZ. EZ data are considered more reliable than those of the Product Board, and hence these were used in further analyses. The PO data were therefore scaled with the ratio of EZ-PO data for the overlapping years (ratio of 1.48) in order to obtain values for those years no EZ are available.

For Veluwerandmeren only EZ data were available, and hence only for the most recent period an estimate could be made. For Grevelingen, eel catches were available from fishermen, made available through Witteveen & Bos on behalf of DUPAN (Stichting Duurzame Palingsector Nederland), for the years 2002-2012 consisting of yellow eel and silver eel weight. For the Grevelingen data for the period 2011-2013 the data from DUPAN and EZ were combined, assuming for 2013 (EZ data) the same silver eel to yellow eel ratio as reported by DUPAN for 2012. The estimated landings for the lakes are shown in Table 3.4.

The percentage yellow eel, in terms of biomass, in the total landings was calculated using length-frequency distribution of the market- sampling of Lake IJsselmeer and Markermeer (2011-2013) and the biological keys as estimated in Chapter 2. This resulted in an estimation that 58% of landings biomass consists of yellow eel and 42% consists of silver eel. This percentage was used to convert the reported total landings of the large lakes (with exception of Grevelingen for which separate estimates were readily available) into landings of yellow eel and landings of silver eel.

*Table 3.4 Estimated mean yearly landings (tonnes) of all eel larger than 30 cm (yellow and silver) in the large lakes, for three time periods, as estimated from EZ/PO-data. * For lake Grevelingen yellow eel (left inside bracket) and silver eel (right inside bracket) were available separately.*

All eel > 30 cm	Period	Mean yearly landings (tonnes)
IJssel-/Markermeer	2005-2007	321
	2008-2010	160
	2011-2013	164
Grevelingen	2005-2007	63 (22/41) *
	2008-2010	19 (11/8) *
	2011-2013	9.5 (9/0.5)*
Veluwerandmeren	2010-2013	11

Standing stock: two scenarios

Estimates of the standing stock of yellow eel (*Table 3.5*) and of silver eel (*Table 3.6*) were subsequently calculated by dividing the landings by the estimated fishing mortality. Two scenarios for fishing mortality were taken into account (*Table 3.3*). These data are integrated into an estimate of the total Dutch standing stock in Chapter 5.

Table 3.5 Estimated mean yearly standing stock of yellow eel larger than 30 cm in the large lakes, for three time periods. For the fishing mortalities of the two scenarios (A and B), see Table 3.3.

Yellow eel > 30 cm	**Period**	**Mean yearly standing stock (tonnes)**	
		Scenario A	Scenario B
IJssel-/Markermeer	2005-2007	276	257
	2008-2010	572	374
	2011-2013	584	382
Grevelingen	2005-2007	33	31
	2008-2010	67	44
	2011-2013	53	34
Veluwerandmeren	2010-2013	40	26

Table 3.6 Estimated mean yearly standing stock of silver eel larger than 30 cm in the large lakes, for three time periods. For the fishing mortalities of the two scenarios (A and B), see Table 3.3.

Silver eel > 30 cm	**Period**	**Mean yearly standing stock (tonnes)**	
		Scenario A	Scenario B
IJssel-/Markermeer	2005-2007	200	186
	2008-2010	414	271
	2011-2013	423	277
Grevelingen	2005-2007	61	57
	2008-2010	49	32
	2011-2013	3	2
Veluwerandmeren	2010-2013	29	19

3.3 Discussion of the demographic model

In the absence of relevant information, it is necessary to assume that vital rates such as immigration, emigration, natural mortality, growth and sex-ratio have remained constant over long periods of time. This is likely to be unrealistic, especially given the fall in recruitment which is likely to have led to changes in rates of immigration and emigration, sex-ratios, natural mortality and growth rates (Edeline et al., 2009; de Leo & Gatto 1996; Davey & Jellyman 2005; Oliveira et al., 2001). Different assumptions on trends in these vital parameters will inevitably lead to different interpretations of length-frequency distributions and stock trends and, therefore, different estimates of fishing mortalities. Some eel population dynamics models exist which explicitly incorporate density dependent processes, such as density-dependent survival of new recruits (glass eels; the DEMCAM model; Bevacqua & de Leo 2006) or density-dependent sex-ratios (the SMEP model; Walker 2006). However, while these models may be more realistic, good quality parameter estimates for these density-dependent processes are not available and it is likely that including more complex processes in the model will only lead to more possible interpretations of the stock trends. Therefore, estimates of fishing mortalities using the population model need to be interpreted with great care, are uncertain.

The model estimates the fishing mortality based on yellow eel because it is assumed that silver eel instantaneous migrate out of the model. However, the survey data used to estimate fishing mortality consists of both yellow eel and silver eel as the survey is carried out in October-November. The mismatch between the model and survey data for larger length classes (*Figure 3.4*, *Figure 3.5* and *Figure 3.6*, *Figure 3.7*) and mean length could just be an artefact of not considering silver eel in the model result or vice versa, excluding silver eel from the survey data. For Lake IJsselmeer holds that the silver eel in the survey data may originate from the large rivers via Rhine and IJssel. For Lake Markermeer holds that the proportion males (see also *Table 2.1*) is lower than the overall assumed proportion males used for both lakes, which decreases the mean length estimate for this lake. However, running the model with a proportion of 0.25 males for the last periods does not result in an increase in mean length. In addition, for Lake Markermeer the number of individuals in the survey has been very low the past decade which has an influence on the usefulness of the estimated fishing mortality for the most recent fishing period.

Compared to the estimates as calculated in 2012 (Bierman et al. 2012), which were done with a constant sex ratio and four fishing periods, the fishing mortality estimates in the most recent period are higher for Lake IJsselmeer and lower for Lake Markermeer. A possible cause for an increase in the fishing mortality estimate lies in a slightly slower growth estimate for males and a less steep maturation (later maturation) curve. This results in slower maturation of males and hence they are part of the fished population for a longer period.

The sensitivity of the model to the biological parameters was discussed earlier (Bierman et al. 2012) and the different estimates presented here make clear that caution is needed when working with this type of model. It also illustrates the need of reliable parameter estimates and the necessity of collecting sufficient biological data from the field. Especially growth rates, maturity at length and sex ratios will affect the transition to the silver eel stage. An increase in the rate of transition to silver eel (earlier maturation) will lead to a lower estimate of fishing mortality. In addition, the influence of migration of silver eels from more upstream parts to Lake IJsselmeer and Lake Markermeer is unknown, but may influence the survey data which are used in the model. The survey takes place end of October and November.

4. A static spatial model for yellow and silver eel

Given the complexity of the Dutch water system with many small catchments and regional-level management a GIS approach was used for the regionally managed waters and the nationally managed rivers and some smaller lakes. This approach was published in Bierman et al. (2012) and Van de Wolfshaar et al. (2014).

This chapter is divided into different analyses based on data availability and their approach: the regionally managed water bodies and the nationally managed water bodies (excluding the four large lakes which are presented in Chapter 3).

Only the main rivers (Rhine, Waal, Meuse and IJssel) and the large lakes (Lake IJsselmeer, Lake Markermeer, Grevelingen and Veluwerandmeren) are managed at a national level in the Netherlands. All other water bodies are managed regionally by the water boards. The monitoring of these water bodies is also markedly different, which led to the necessity to different methods of standing stock estimation for nationally and regionally managed water bodies.

The regionally managed freshwater water bodies make up 65% of the total freshwater surface area (PBL, 2010), but these waters were not surveyed in a regular and standardised manner before the implementation of the European Water Framework Directive (WFD) in 2000 (2000/60/EC). The nationally managed rivers are monitored in a standardized manner since 1990. For the four large lakes survey data were not available or deemed unsuitable. Therefore, stock estimates were based on commercial catch data and fishing mortality estimates as based in the demographic model (Chapter 3).

For both regional and national waters, the estimation of the standing stock had two distinct elements: estimation of the density of eel (kilogram per hectare) and estimation of the amount of water surface area. Density of eel was divided into density of silver eel and yellow eel, via the biological keys as defined in Chapter 2. The standing stock was subsequently estimated for three scenario's, in which assumptions had to be made for the catch efficiency of the survey gear and the spatial distribution of eel in a water body. These scenario's will first be discussed, followed by the estimations for the regionally managed waters and the chapter will end with the estimations for the nationally managed waters.

The results of this chapter feed into the estimates of the Dutch stock (Chapter 5)(*Figure 4.1*).

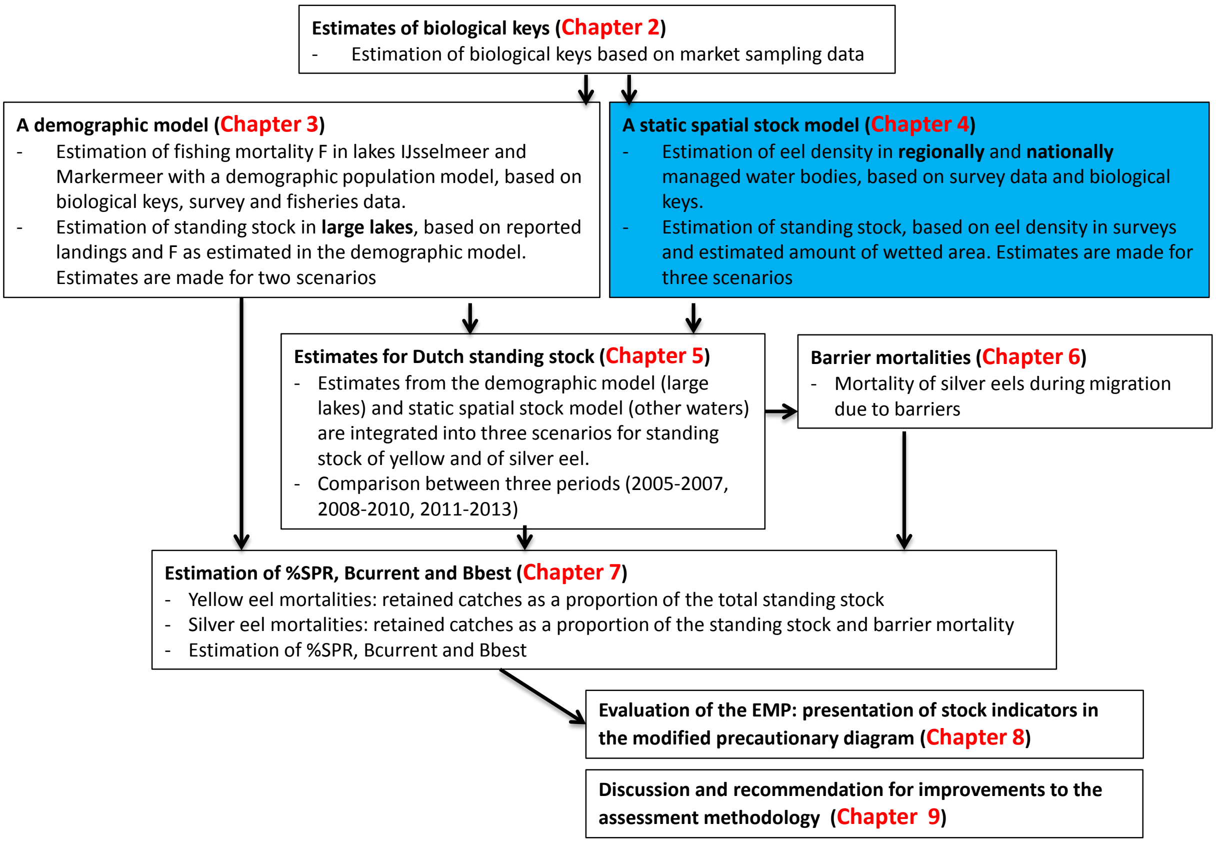

Figure 4.1 Flow chart of the assessment procedure.

4.1 Three scenario's for the static spatial model

Three scenarios were run with different estimates for the catch efficiency of the electric dipping net and the habitat preference of eel.

Catch efficiency

No survey gear has a catch efficiency of 100%. Catch efficiencies of electric dipping are likely to depend on the type of water body, the substrate, the time of day, the settings of the gear, and the experience of the staff operating the gear (Beaumont et al., 2002). Here, for the electric dipping net, a best guess for catch efficiency of 20% is used, as set by the Dutch "Stichting Toegepast Onderzoek Waterbeheer", the research platform for the Dutch regional water managers (Handboek Visbemonstering, STOWA 2003). Estimates of catch efficiencies of eel using electric dipping nets are scarce in the scientific literature and may be specific to the type of water body, habitat, and gear. Naismith & Knights (1990) assumed a catch efficiency for eel using electrofishing gear of 27% in a river, whereas Baldwin & Aprahamian (2012) estimated efficiencies of approximately 60% in small rivers. Aprahamian (1986) showed size-selective effects of electro-fishing, with estimated mean probabilities of capture from 0.36 for the smallest (youngest) eels to 0.59 for the largest (oldest). Carrs et al. (1999) reported estimated capture probabilities of 0.715 and 0.751 for lochs and streams respectively. Stevens et al. (2009) in an evaluation of the Belgian eel management plan assumed catch efficiencies of 66%.

Habitat preference

The habitat preference is an important factor determining how to scale estimates from biomass in the survey samples in the borders of a water body, to estimates of the biomass for an entire water body. The simplest case to scale from samples to water body level is when catches in biomass per hectare are scaled linearly to water body surface area. This method assumes eels have no habitat preference. However, eels may prefer the littoral over the open water, and almost all samples were obtained during fishing operations with electric dipping nets near the shores of lakes or banks of rivers, streams or canals. The electric dipping net data is therefore taken as representative for eel densities near the shores or banks, whereas eel densities further from shores or banks are likely to be lower (Jellyman & Chisnall 1999, Schulze et al., 2004). Therefore, a scaling was done using a correction fraction to account for differences in eel density between the littoral zone ('inshore') and the open water ('offshore'). How is eel distributed over a water body? Literature on this subject is scarce and focusses on the relation between eel density and distance to shore, mainly in lakes. Contradicting results were found for lakes; Chisnall & West (1996) found that eel densities off shore in New Zealand lakes were on average 40% of those inshore; Schulze et al. (2004) found a decrease in number with depth for a reservoir, but did not take distance to shore into account; Jellyman & Chisnall (1999) and Yokouchi et al. (2009) both found a positive relationship between catch per unit effort and distance to shore. A recent, still unpublished, report of the Inland Fisheries Ireland Eel Monitoring Programme on 13 Irish lakes found differences between lakes and overall no relationship between density and distance to shore (Oleary personal communication). In the national eel management plans, different relations are used. In Belgium the biomass near the shore is set to be a fraction (up to roughly 33%) of the total biomass in a water body (Stevens et al., 2009). In France no difference is made between shore and non-shore areas in rivers given the lack of evidence otherwise (pers. comm. C. Briand).

Three scenarios

Taking into account the uncertainty regarding the catch efficiency of the electric dipping net and the habitat preference of eel, estimates of standing stock sizes were computed using three different scenarios (*Table 4.1*). In these scenarios, the catch efficiencies and habitat preferences are varied according to results from the literature (see above). For the catch efficiency, while we use 20% as our best guess estimate, we also compute estimates in a scenario in which catch efficiencies were assumed to be 66%. For the habitat preference, we assumed the density in the offshore area to be 33%, 50% or 66% of the densities in the inshore area (i.e., within 1.5 meters of shores/banks).

In scenario 1 the highest catch efficiencies (66%) and lowest proportion of eel in the offshore area compared to the inshore area are used, and this scenario will therefore lead to the lowest estimated standing stock of eel. In scenarios 2 and 3 the best guess estimates for catch efficiencies are used (20%), with the proportion of eel in the offshore area compared to the inshore area of 50% and 66% respectively. Scenario 3 will therefore lead to the highest estimates of standing stock.

Scenario 2 is the best guess estimate. All stock estimates made in tables etc. will be calculated according to scenario 2, unless stated otherwise.

Table 4.1 The three main scenarios used in the approach to stock assessment in which survey data are scaled to wetted areas. A best guess of 20% for catch efficiencies was used with an upper limit of 66%. Densities in areas of water bodies outside 1.5 meters of the shore/bank ("offshore area") were assumed to be either 30%, 50% or 66% of densities within 1.5 meters of the shore/bank ("inshore area").

Catch efficiency	**Density "offshore" compared to "inshore"**		
	33%	**50%**	**66%**
66%	Scenario 1		
20%		Scenario 2	
20%			Scenario 3

4.2 Regionally managed water bodies

GIS data

The eel biomass in the regionally managed water bodies was assessed in the same way as presented in Bierman et al. (2012) and Van de Wolfshaar et al. (2014). It is based on GIS information of Water Framework Directive (WFD) water bodies and the WFD fish sampling. The regional management of waters is executed by so called water boards (*Figure 4.2*).

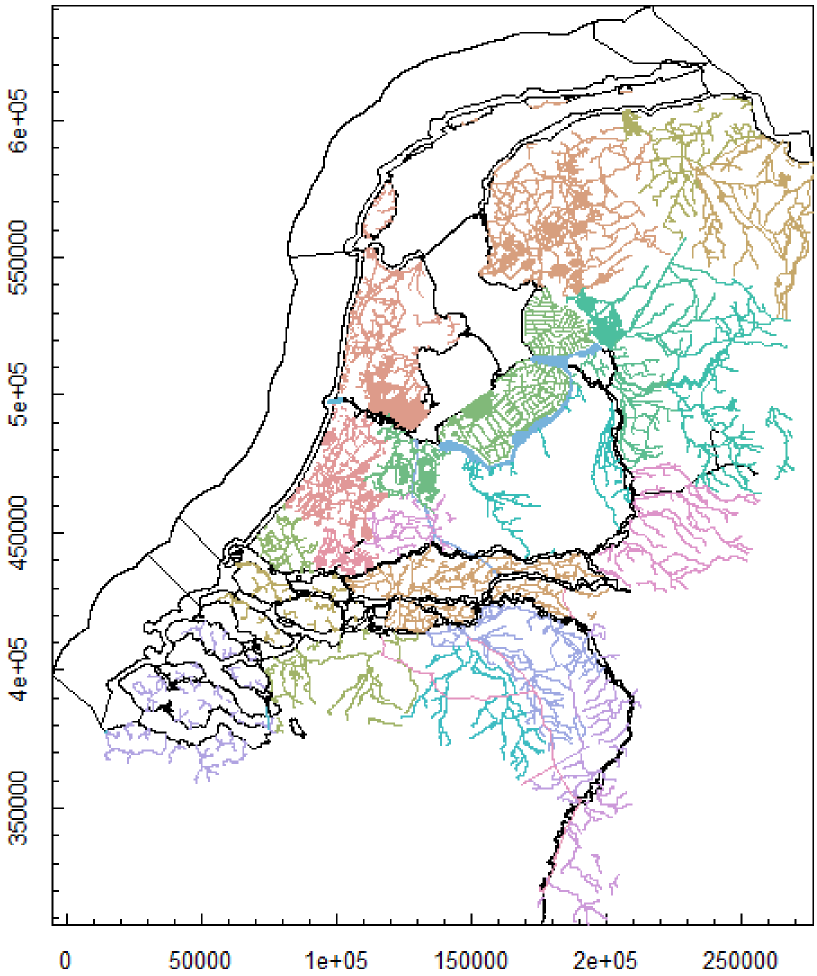

Figure 4.2 Water bodies included in the model, the colors represent different management regions, in black are the nationally managed waters

In the Netherlands all WFD water bodies are assigned to a water body type. Data were assimilated per water body type. The method of Bierman et al. 2012 was followed (see also Van de Wolfshaar et al. 2014).

Only 0.5% of the ditches are surveyed within the WFD survey program and therefore additional information on the ditches is needed. In the report of Bierman et al. (2012) the width of the ditches was not accounted for by the WFD and was not taken into account. In this report the width of the ditches is included based on the TOP10 map (RWS) (Winter et al. 2013a) (*Table 4.2*). The TOP10 map has more detailed information of all waters of the Netherlands, including the WFD waters. Similar to the WFD maps there is a map with polygons and a map with line elements. Of the line element map the categories line with width 0.5-3m and width 3-6m were considered as ditch. Of the polygon map the category ‘waterway’ width more than 6m was taken into account. For these three categories all water bodies that are already accounted for in the WFD map were discarded to prevent double entries.

Table 4.2 Overview of the length (in km) and surface area (in ha) for the three types of ditch, after removal of WFD water bodies. For the category ‘waterloop’ >6m width the surface area provided by the polygon map was used. For the line categories width 0.5-3 m and width 3-6 m an average width of 1.75 and 4.5 m was used, respectively.

Category	Length (km)	Surface area (ha)
0.5-3	148116	25920
3-6m	24090	10841
>6m	39627	22681
Total	211834	59441

Survey data

Eel sampling within the regionally managed WFD waters was done following an EU certified protocol (STOWA Handboek Visstandbemonstering 2003) using electrofishing. Sampled water bodies are representative for water types as defined in WFD regulation.

Dutch regionally managed water bodies fall within one of the 22 water boards of the Netherlands. Sample data were obtained from one of the companies hired by several of the water boards to conduct WFD fish sampling and from the water boards directly in case there data was not included already. Out of 14 water boards addressed individually two water boards did not provide data or provided data too late for processing. Of the data from the 12 water boards that did respond four sets were not usable (processed data, incomplete data or too low spatial precision) and for one dataset assumptions had to be made for the sampled area estimate based on gear type (STOWA Handboek Visstandbemonstering 2003). Seven provided datasets which were ready to use on delivery. It is important to note that not all water boards sample every year. Data of some regional water boards was not available and therefore not considered in this analysis.

Sampling occasions need to be located within WFD water bodies as defined in the Polygon and Line maps. This was checked using the geographic coordinates of the electro fishing sampling event. Firstly, coordinates which fell into a polygon were assigned to that polygon. Secondly, for the sampling events which could not be assigned to a polygon, the distance to line segments was computed, and the sampling event was assigned to the nearest line segments as long as this was within 25 meters of the sampling occasion. Thirdly, for all remaining sampling events without a match the water body names given at the time of the data collection were used. For regional waters, this results in 3583 electrofishing events that were used for the eel assessment (*Table 4.3*). These cover the period 2006-2013 and their locations are presented in *Figure 4.3*.

Table 4.3 Number of electro fishing events per year available in the regional data set.

2006	2007	2008	2009	2010	2011	2012	2013
373	319	218	538	424	568	623	520

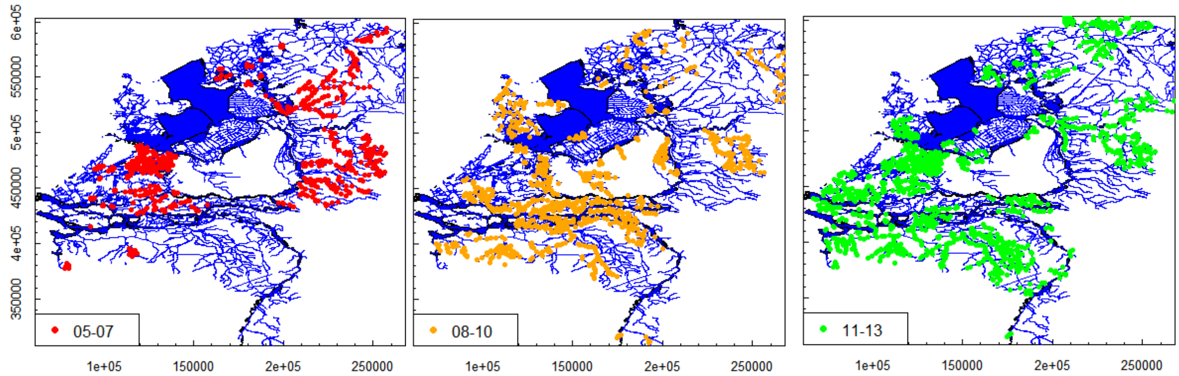

Figure 4.3 Geographical location of available sample points across the Netherlands in WFD-waters for the different periods, 2005-2007, 2008-2010 and 2011-2013.

From *Figure 4.3* it is clear that the sampling effort differs between periods and regions. Of some regions no data are available, while other regions have available data for all periods. Also, the regional coverage is highly variable. *Table 4.4* illustrates the data availability for the present study per water board and per year. The water boards follow the six year cycle of the Water Framework Directive which schedules their monitoring actions.

Table 4.4 Sampling data availability per water board and per year indicated by a green colour. Note that not all water boards sample each calendar year and that some water board-year combinations were not available for analysis.

Water board	2006	2007	2008	2009	2010	2011	2012	2013
Aa en Maas				■			■	■
Brabantse Delta	■	■	■		■	■	■	■
De Dommel				■	■	■	■	■
Groot Salland						■		
Hollandse Delta	■						■	■
Hoogh. Amstel, Gooi en Vecht	■	■	■	■	■		■	■
Hoogh. De Stichtse Rijnlanden	■		■	■	■		■	■
Hoogh.Hollands Noorderkwartier			■	■	■	■		
Hoogh. van Delfland			■			■	■	
Hoogh. van Rijnland	■	■		■		■	■	■
Hoogh. van Schieland en de Krimpenerwaard	■	■	■	■	■	■	■	■
Hunze en Aa's		■	■					
Peel en Maasvallei					■	■	■	■
Reest en Wieden	■	■	■	■	■			
Rijn en IJssel	■	■						
Rivierenland		■		■	■		■	
Roer en Overmaas			■		■			■
Vechtstromen		■	■		■	■	■	■
Waterschap Vallei & Veluwe			■	■	■	■		
Wetterskip Fryslân	■			■			■	
Zuiderzeeland					■			■
Noorderzijlvest						■	■	■

The variability in the area sampled is large between water types (*Table 4.5*) (see Appendix A for a description of the types). In general, the water types with the largest surface area have a high sampled surface area. Yet, representing the sampled area per water type as a percentage of the total surface area of all water types, it can be low (e.g. type R5, with 84 ha sampled, while the type R5 itself represents only 2% of the total water surface; M14 represents 43% of the total water surface area yet 28 ha is sampled.). Water types contributing with a large surface area are not sampled with more effort, yielding over- and under-representation of water types (represented as the % sampled of total sampled area).

When breaking the data up into periods the % sampled of the total area sampled illustrates the effort distribution per water type and per period over the total sampled area.

Table 4.5 The distribution of the sampling effort over the water types. Area = surface area of the water type. % of Total Area per type = Percentage that the surface area of a water type represents of the sum of areas. Total area sampled (ha) = the total area sampled in all sampled years. % sampled of total sampling effort = the percentage of the area sampled per water type relative to the total area sampled, given the period. (see Appendix A for a description of the types)

	Total Area (ha)	% of Total Area	Area sampled (ha) All years	% sampled of area sampled			
				All years	05-07	08-10	11-13
M10	979.1	2.18	35.33	10.12	8.08	5.87	14.57
M14	18848.2	42.91	27.51	7.88	7.52	8.72	7.34
M1a	132.3	0.29	16.51	4.73	2.21	7.37	3.66
M2	8.8	0.02	1.07	0.31	-	0.84	-
M20	2255.1	5.01	4.93	1.41	1.47	0.90	1.81
M23	48.9	0.11	0.26	0.08	-	-	0.17
M27	11444.9	25.45	20.75	5.94	11.66	3.61	5.34
M3	2089.3	4.65	56.51	16.19	7.98	21.02	15.83
M30	1188.5	2.64	0.72	0.21	-	-	0.47
M6a	357.8	0.80	12.05	3.45	3.55	2.40	4.29
M6b	1037.0	2.31	16.53	4.74	9.49	2.07	4.84
M7a	7.7	0.02	0.19	0.05	0.00	0.00	0.12
M7b	1866.4	4.15	7.85	2.25	2.12	3.25	1.48
M8	647.9	1.44	15.45	4.43	2.48	2.17	7.17
R12	47.2	0.10	1.45	0.42	1.42	-	0.31
R13	4.4	0.01	-	-	-	-	-
R14	11.5	0.03	0.36	0.10	-	0.14	0.12
R15	22.0	0.05	-	-	-	-	-
R17	7.3	0.02	-	-	-	-	-
R18	38.0	0.08	4.38	1.25	-	2.69	0.62
R4	73.0	0.16	13.16	3.77	0.81	3.59	5.24
R5	892.2	1.98	84.32	24.16	35.76	24.16	19.00
R6	1804.3	4.01	27.32	7.83	5.45	10.55	6.62
R7	1151.7	2.56	1.63	0.47	-	0.08	1.00
R8	12.2	0.03	0.72	0.21	-	0.56	-
Total	44976		349				

Based on the monitoring data, the length-weight relationship and sampled surface areas, the biomass production of eel larger than 30 cm was calculated for each water type, for each scenario.
Some water types were not sampled (R13, R15, and R17). For these water types the production averaged over all other water types was used. In addition, the sampling data were aggregated for each water board. As for some water boards information was unavailable the production averaged over all other water boards was used for those lacking information.

In addition to the WFD sampling program an additional sampling of ditches was done in 2013 and 2014 because ditches are little sampled within the WFD sampling program (Van Keeken 2014a, 2014b). In order to estimate the standing stock in ditches the data from the WFD sampling (types 'M1a and M2) was combined with the data from the ditch sampling survey. As the data from the additional ditch sampling was insufficient to use the length frequency distribution to assess silver eel biomass, the average percentage of silver eel based on the regional data was used (24%).

Results; density and standing stock

The density data per haul were converted from number per length to weight using the length-weight conversion function (Chapter 2).
Using the identical approach as used in the assessment in 2012 (Bierman et al. 2012, Van de Wolfshaar et al. 2014) the biomass of eel was calculated per water type and per water board. The eel biomass present in ditches was done separately, based on the ditch sampling program (Van Keeken et al. 2014a, 2014b). Based on the water types a total of 2394 tonnes eel (>30 cm) is estimated for the regional waters (Table *4.6*).

Table *4.6 Eel biomass estimates per water type (for 2005-2013). Total area = water surface area of a water type in the Netherlands. Density = density as caught in the surveys. Biomass = density in survey x total area (corrected for inshore-offshore). Stock assessment, estimate of total biomass of eel > 30 cm (yellow and silver eel) per water type following scenario 2 (see Table 4.1). * based on a 24% silver eel out of all eel from the water types.*

Water type	Total eel (>30cm)		Silver eel (>30cm)	
	Density (kg/ha)	Biomass (efficiency and inshore-offshore corrected) (tonnes)	Density (kg/ha)	Biomass (efficiency and inshore-offshore corrected) (tonnes)
M10	6.6	32.5	1.4	6.7
M14	21.0	1116.4	5.2	276.7
M1a	1.2	0.8	0.5	0.3
M2	5.1	0.2	1.7	0.1
M20	12.7	142.8	2.8	31.0
M23	0.0	0.0	0.0	0.0
M27	9.5	546.4	2.3	128.9
M3	4.2	43.9	1.4	14.6
M30	3.5	39.8	0.3	3.3
M6a	3.4	6.1	1.3	2.4
M6b	8.6	44.7	2.0	10.4
M7b	7.5	69.9	1.4	12.6
M8	0.7	2.4	0.6	1.8
R12	14.9	3.5	3.0	0.7
R14	1.5	0.1	0.2	0.0
R18	6.8	1.3	2.3	0.4
R4	2.4	0.9	0.7	0.2
R5	3.7	16.6	1.2	5.3
R6	11.7	105.3	2.8	25.5
R7	38.0	218.7	10.6	60.9
R8	3.8	0.2	2.3	0.1
M7a	3.0	0.1	0.2	0.0
R13	7.7	0.2	2.0	0.0
R15	7.7	0.8	2.0	0.2
R17	7.7	0.3	2.0	0.1
Subtotal		2394		582
Ditches	4.8	1268		304*
TOTAL		3662		886

Based on the ditch sampling campaigns (Van Keeken 2013, 2014) an estimate of 0.01 kg/ha was calculated. By adding the biomass density estimates for the type M1a and M2 and weighing by sampled surface area an estimate of 4.8 kg/ha is calculated for the eel density as caught in surveys in ditches. Following scenario 2, an estimate of 1268 tonnes is made for eel (yellow and silver) in ditches (surface area not accounted for in the WFD) (Table *4.6*).

In addition to an estimate based on water type, an estimate was made for all eel (> 30 cm) based on water board, as the water boards manage the regionally waters. The results are presented in *Table 4.7* and differ slightly from the estimate based on water type. The estimate based on water type will be used in further calculations.

Table 4.7 Biomass of eel > 30 cm based on all sampling data (no periods considered) assessed per water board Ditches are not included. Since the report of 2012 some water boards merged and here only the current water boards are included providing less water boards but equal surface area compared to Bierman et al. (2012).

Water board	Density (kg/ha)	Biomass (efficiency and inshore-offshore corrected) (tonnes)
Aa en Maas	1.4	2.2
Brabantse Delta	20.8	22.5
De Dommel	1.7	2.2
Groot Salland	34.2	218.3
Hollandse Delta	9.8	20.8
Hoogheemraadschap Amstel, Gooi en Vecht	6.9	147.6
Hoogheemraadschap De Stichtse Rijnlanden	5.3	3.7
Hoogheemraadschap Hollands Noorderkwartier	11.0	122.6
Hoogheemraadschap van Delfland	7.4	6.7
Hoogheemraadschap van Rijnland	13.2	151.0
Hoogheemraadschap van Schieland en de Krimpenerwaard	6.7	20.7
Hunze en Aa's	5.7	35.3
Peel en Maasvallei	11.4	7.1
Reest en Wieden	4.1	116.9
Rijn en IJssel	2.3	3.9
Rivierenland	4.2	10.5
Roer en Overmaas	5.3	2.2
Vechtstromen	9.4	71.1
Waterschap Vallei & Veluwe	2.9	3.8
Wetterskip Fryslân	21.2	882.0
Zuiderzeeland	20.4	430.6
Noorderzijlvest	8.7	68.2
Kanalen	9.7	84.1
Scheldestromen	9.7	0.3
TOTAL		2434

Standing Stock in regionally managed waters

As in Bierman et al. (2012) different scenarios are used to estimate the eel biomass (*Table 4.1*), based on different values of catch efficiency and the ratio between eel densities in shores and open water. Eel biomass estimates vary between scenarios, with scenario 1 providing the low estimate and scenario 3 a high estimate for eel biomass (*Table 4.8*). In addition to the different scenarios, estimates were done for different periods and for all data combined. The variation in biomass estimate between periods is high. Because of the large variation in sampling effort per water type and/or period, the variation in biomass estimate is most likely driven by the variation in sampling, rather than a change in the eel population (see also *Table 4.3*, *Table 4.4*, *Table 4.5* and *Figure 4.3*). Because of this uncertainty the estimate of all years combined will be used in further analysis.

*Table 4.8 Estimates of standing stock of eel in the regionally managed waters; all eel larger than 30cm eel and silver eel (>30cm) biomass estimates (tonnes) for the three periods and the three scenario's. The most left column shows the estimates for eel in ditches. Due to the low number of eels in the ditch sampling biomass estimates were made on all eel, and no differentiation to silver eel was made. Total biomass estimates are based on the analyses per water body type. *based on the 0.24 ratio silver to all eel from the other water types (*Table *4.6).*

	Ditch only	All years	05-07	08-10	11-13
> 30 cm eel					
Scen 1	366	493	306	306	717
Scen 2	1268	2394	1488	1480	3513
Scen 3	1324	3116	1937	1921	4593
> 30 cm silver eel					
Scen 1	88*	120	70	60	174
Scen 2	304*	582	338	289	854
Scen 3	318*	764	421	386	1125

4.3 Nationally managed water bodies

<u>Survey in the main rivers</u>

Within the governmental survey program "Biologische Monitoring Zoete Rijkswateren", fish species in the main Dutch rivers are monitored yearly (*Figure 4.4*). Among others, rivers are sampled using research vessels (the "Actieve Monitoring van de Zoete Rijkswateren" survey, e.g., van der Sluit et al., 2014). Sampling in the open water takes place using a beam trawl and in the riverbanks using an electric dipping net. However, the beam trawl is not very suitable for sampling eel and only data collected with the electric dipping net are used here. Both the main rivers and water bodies connected to the main rivers are sampled (*Table 4.9*). Sampling takes place in autumn and early spring. There are six regions that have been sampled consistently and yearly since 1992. A region is usually sampled in the same months, but different regions are sampled in different months. There are also regions which have been sampled from a later year onwards and for which data is only available for some of the three years that are considered here. Volkerak-Zoommeer is an extreme example; it has not been sampled in 2011-2013 and thus the estimate for 2008-2010 was used. However, this estimate was based on two years (2008 and 2010) in which the water was samples in different months (March in 2008 and September in 2010). See *Figure 4.4* for the classification of regions and *Table 4.9* for an overview of survey details per region. The large lakes IJsselmeer and Markermeer are sampled in another national survey program, using an electric beam trawl. However, because no information on the catch efficiency of this gear is available, density estimates from the fisheries model are used instead (see Chapter 3). The large lakes Grevelingen and Veluwerandmeren were only sampled with other types of gears (normal beam trawl, seine and fyke), the efficiency of which are even lower for eel, and less certain. Thus, the density estimate for these lake are also derived from the demographic model (see Chapter 3).

Density per haul is determined (kg/ha), using eel length and the estimated length-weight conversion factor (see chapter 2). These densities are averaged per region and per type of water (main waterway and connected water body), over all samples of the three focus years. See *Table 4.9* for the density estimates per region for all caught eel. Note that catch efficiency has not been corrected for yet in this table.

Various changes were made in the methodology since the last report. Most importantly, the definition of year has been changed. In 2012 survey-year was used as definition of year (i.e., the survey took place from October to May, and the survey-year was marked as the year of the January-May sampling), while in the present report calendar year was used. Given the strong variation in density between years, this sometimes had large effects on the estimated density per period. Also, the altered biological keys had significant effects on the estimated biomass (see chapter 2).

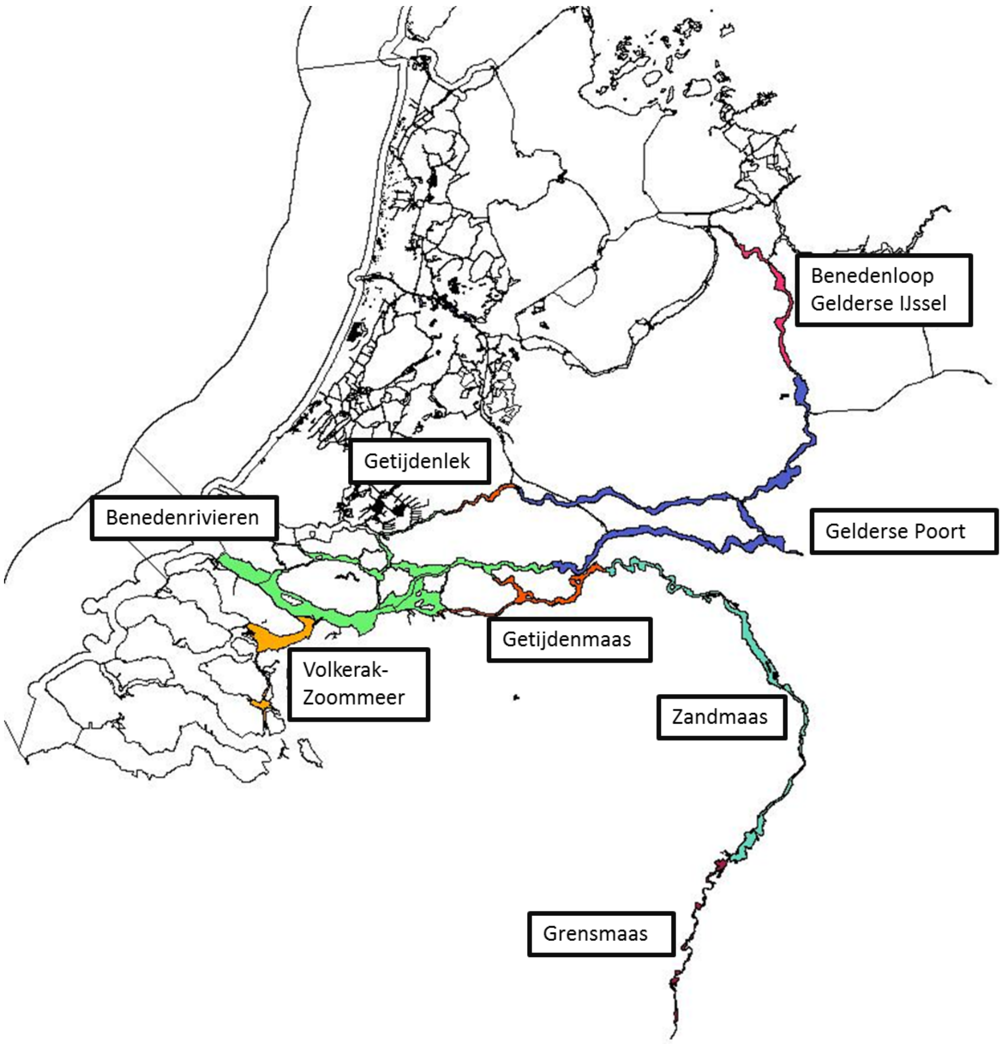

Figure 4.4 Classification of the main rivers. Regions are represented by different colours.

*Table 4.9 Survey information per river region and type of water (main waterway or connected water body), for the years 2011, 2012 and 2013. Sampled years = the years in which a region has been sampled, where all = 2011+2012+2013. Sampled months = the months in which a region is sampled (in 2005-2010 different neighbouring months may have been used). No. samples = the total number of samples collected in the sampled years. Survey density in riverbank = density for all eel larger than 30 cm (yellow and silver). Survey density is based on data collected using an electric dipping net in the riverbanks. No correction for catch efficiency of the gear is made yet. * = Volkerak-Zoommeer has not been sampled in 2011-2013 and the estimate for 2008-2010 was used. This estimate was based on a march survey in 2008 and a September survey in 2010. See also Table 4.12.*

Region	Water	Sampled years	Sampled months	No. samples	Survey density (>30 cm) in riverbank (kg/ha)
Benedenloop Gelderse IJssel	main	all	2, 3	17	1.40
	connected			3	1.01
Benedenrivieren	main	2011, 2012	10	43	6.82
	connected			4	4.36
Gelderse Poort	main	all	3, 4	94	2.62
	connected			40	1.31
Getijdenlek	main	2011, 2012	10, 11	19	8.94
	connected			2	0.00
Getijdenmaas	main	2011, 2012	10, 11	35	3.49
	connected			5	1.31
Grensmaas	main	all	5	33	21.47
	connected			3	5.10
Volkerak-Zoommeer	main	(2008, 2010)*	3,9*	18*	44.01*
Zandmaas	main	2011, 2012	4	28	7.82
	connected			14	13.61

GIS data

Three types of geographical information are collected. The surface area (ha) and bank length (km) of the rivers and lakes are calculated (*Table 4.10*) using GIS-data (the Ecotopenkaart of Rijkswaterstaat). For the rivers, extra information on bank length was collected (*Table 4.10*). In some parts of the rivers, bank length is significantly larger than river length because of groynes ("kribben") placed perpendicular to the riverbank. These groynes are approximately 90 meters long and placed 200 meters apart (www.rws.nl). In the parts of the rivers with groynes, bank length is thus approximately 1.9 times the river length. By visually scanning satellite images of Google Earth, a rough estimate of the percentage of riverbank with groynes is made: 60% of the Gelderse Poort is estimated to have groynes, and 50% of the Getijdenmaas. The other regions are assumed to have no groynes.

Table 4.10 Surface area, river length and bank length per river region. Groynes = the percentage of a region that has groynes. Bank length is river length with groyne length (1.9 times the river length) included.

Region	**Waterbody**	**Surface area (ha)**	**River length (km)**	**Groynes**	**Bank length (km)**
Benedenloop Gelderse IJssel	main	675	118		118
	connected	271	42		42
Benedenrivieren	main	18377	703		703
	connected	1670	498		498
Gelderse Poort	main	5201	557	60%	858
	connected	1468	191		191
Getijdenlek	main	500	52		52
	connected	78	19		19
Getijdenmaas	main	1265	155	50%	224
	connected	753	82		82
Grensmaas	main	426	135		135
	connected	436	49		49
Volkerak-Zoom	main	4814	171		171
Zandmaas	main	2043	305		305
	connected	1413	160		160

Synthesis

Densities are corrected for the catch efficiency of the electric dipping net (20% for scenario 2). Water surface area is divided into two areas: littoral zone and open water. The width of the littoral zone is set equal to the reach of the dipping net (1.5 meters) and its surface area is the width times the bank length. The open water surface area is the total surface area minus the surface area of the littoral zone. Eel density outside the littoral zone is assumed to be a fraction of that in the littoral zone (50% for scenario 2). Subsequently, density is converted to absolute biomass (kg) for the riverbank and open water surface areas separately. Alterations are made for the Grensmaas. For Grensmaas no correction for habitat preference is made and density in the open water is assumed to be equal to that in the littoral zone, because sampling with the dipping net takes place in the open water in this (shallow water) region and is thus representative for the open water densities.

Biomass of silver eel and of all eel larger than 30 cm is estimated according to scenario 2 (*Table 4.11*). No information on the ratio yellow eel - silver eel in the surveys is available and the conversion keys as estimated in Chapter 2 is used to determine the biomass of silver eel.

*Table 4.11 Biomass of all eel, eel larger than 30 cm and silver eel (tonne) per river region, estimated according to scenario 2, for 2011-2013. *estimate for 2008-2010 was used because no estimate for 2011-2013 was available.*

Region	Biomass all eel	Biomass eel >30cm	Biomass silver eel > 30cm
Benedenloop Gelderse IJssel	3.12	3.12	0.39
Benedenrivieren	333.91	329.55	58.83
Gelderse Poort	39.81	39.70	9.79
Getijdenlek	11.36	11.26	1.95
Getijdenmaas	13.84	13.78	2.01
Grensmaas	56.85	56.84	22.73
Volkerak-Zoom	532.48	498.30*	81.17
Zandmaas	89.74	89.63	31.70

For scenario 2, estimated biomass of eel larger than 30 cm in the period 2011-2013 is also compared to the periods 2005 - 2007 and 2008 -2010 (Table 4.12). No consistent trends is found in the estimated biomass through time.

*Table 4.12 Biomass of eel larger than 30 cm (yellow and silver) in tonne per river region, for the current period, and two periods previous (2008-2010) and (2005-2007). Biomass estimated with scenario 2. * the estimate of 2008-2010 was used for both 2005-2007 and 2011-2013. ** the average of the estimates of 2008-2010 and 2011-2013 was used in further analyses.*

Region	Biomass 2005-2007 eel >30 cm	Biomass 2008-2010 eel >30 cm	Biomass 2011-2013 eel >30 cm
Benedenloop Gelderse IJssel	11.88	4.06	3.12
Benedenrivieren	397.60	346.32	329.55
Gelderse Poort	17.78	4.03	39.70
Getijdenlek	3.28	4.51	11.26
Getijdenmaas	34.83	13.54	13.78
Grensmaas	35.56	113.97	56.84
Volkerak-Zoom	*	498.30	*
Zandmaas	**	105.92	89.63

4.4 Discussion

Regionally managed waters

There are some shortcomings and uncertainties in the data availability concerning the regionally managed waters. The first issue is that not all collected data was available for the analysis presented here. A second issue is, given the six year cycle of the WFD monitoring and the three year cycle for the eel stock assessment, that not all water types are equally represented for the periods used in the eel stock assessment. This means that some types are over- and some types are under-represented if using the data at the three year interval as intended for the eel assessment. In addition, not every sampling occasion could be linked to a water body and these were excluded from the analysis. This mismatch might be due to measurement error in GPS equipment or errors in data entry. As in 2012, scenarios were used for catch efficiency and habitat use, issues that remain uncertain. The new set of biological keys, based on more individuals, had an effect on the estimates of yellow and silver eel of the regionally managed waters.

Nationally managed waters

There are some shortcomings and uncertainties in the methodology used for the nationally managed waters.
Different river regions are surveyed in different months. This implies different mean water temperatures, different eel behaviour, and different silver eel migration activity, all of which can influence the catches. Various regions are not sampled every year, which makes the estimate per period less reliable. For two regions (Volkerak-Zoommeer and Zandmaas), information was not available for every period and densities were assumed to have stayed equal compared to other (sampled) periods. The most extreme example is Volkerak-Zoommeer, which was (a) only sampled in two of the nine years (of 2005-2013), (b) only sampled in one period (2008-2010) and (c) sampled in different months in the two years (September in 2010 and may in 2008).

A central assumption underlying the stock estimation is that the eels caught in a certain area represent the inhabitants of that area, using it to realise their growth until seaward migration. For the main passage way of silver eel to the sea (i.e., almost all nationally managed rivers and lakes), this assumption entails much uncertainty. On the one hand, eels surveyed during the migration season (i.e., in many of the rivers; see table 4.9) may partly consist of migrating silver eels travelling from other areas where they spent their yellow eel years. These eels were perhaps surveyed in their original habitats too (since areas are surveyed in different time periods), or their habitat may have been located in other countries. This would lead to an overestimation of the silver eel stock of the Netherlands.
On the other hand, another related uncertainty in the used methodology is that all areas surveyed during or directly after the migration period may lead to an underestimation of the silver eel stock. Part of the silver eels might have migrated away or be in parts of the water body that are not surveyed with the dipping net (the open water), and some eels that migrate later in the season might still be too small to be defined as silver eel (for sites that are monitored before the main migration period). Thus, the fact that both main surveys in the nationally managed waters (in the IJssel-/Markermeer and the main rivers) take place predominantly during the migration period may lead to a systemic underestimation of the silver eel stock. The same reasoning goes for the regionally managed waters surveyed during or following the migration period. However, this does not affect trends in biomass. Information on the amount and distribution of groynes in the rivers is lacking. Here we used a very coarse method to estimate the amount of groynes per region.

Various changes were made in the methodology since the last report. Most importantly, the definition of year has been changed. In 2012 survey-year was used as definition of year, while in the present report calendar year was used. Given the strong variation in density between years, this sometimes had large effects on the estimated density per period.

5. Stock estimate for the Dutch standing stock

In this chapter the total Dutch stock estimates are done, based upon the information for all water bodies as described in the previous chapters (*Figure 5.1*). The results of this chapter in turn feed into Chapter 6 and 7.

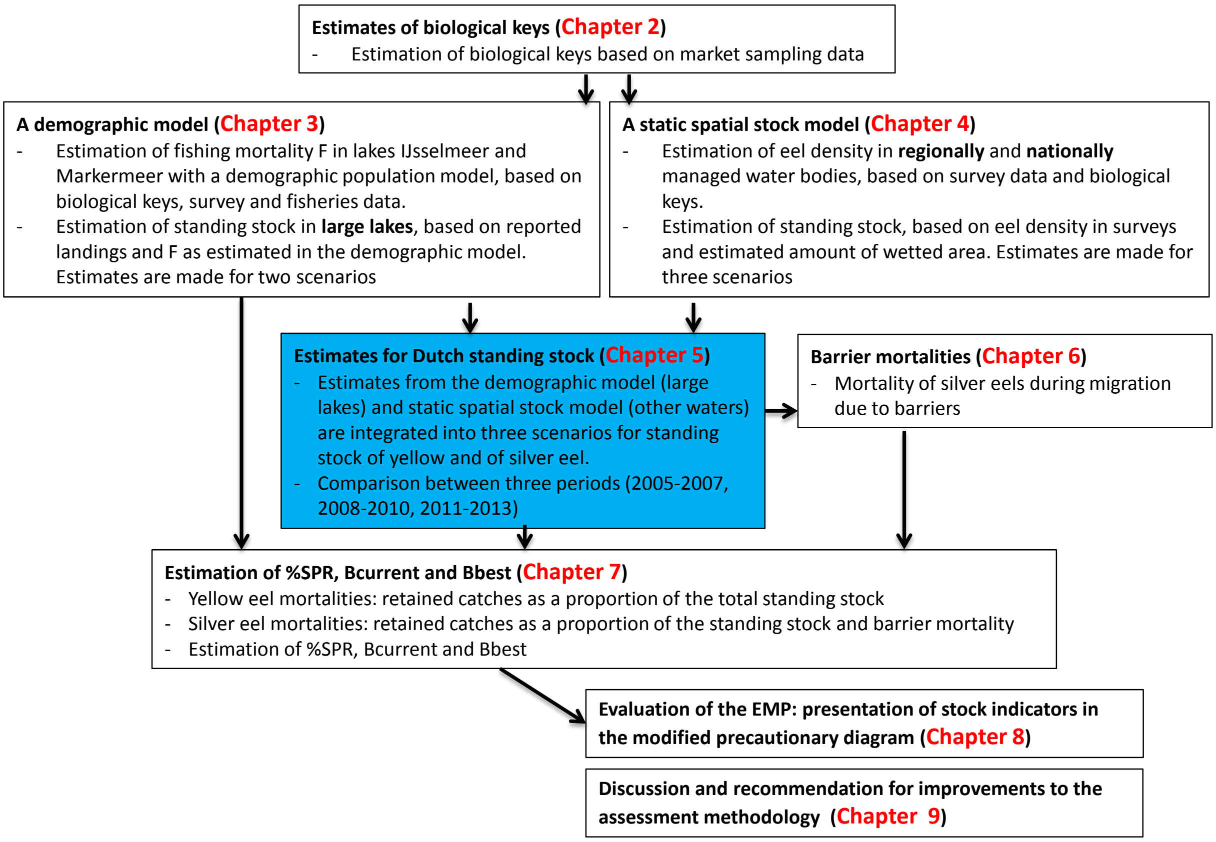

Figure 5.1 Flow chart of the assessment procedure.

5.1 Three scenarios and three time periods

<u>Three scenarios</u>

For the estimation of the standing stock in the large lakes (i.e., Ijsselmeer, Markermeer, Randmeren and Grevelingen. See Chapter 3), two scenarios were run with regard to the fishing mortality (*Table 3.3*). For the estimation of the standing stock in the other waters (regionally managed waters and the nationally managed rivers), three scenarios were run with regard to catch efficiency and habitat preference (*Table 4.1*). These scenarios are integrated into three overall scenarios with varying fishing mortality, catch efficiency and habitat preference (*Table 5.1*). Scenario B of the large lakes (table 3.3) was used for both scenario 1/B and 2/B, while scenario A of the large lakes was only used for scenario 3/A.

Of these three scenarios, the standing stock estimates of scenario 2 is taken as the best guess estimate. Scenario 1 is taken as the minimum estimate and scenario 3 as the maximum estimate, identical to Bierman et al. (2012).

Table 5.1 The three main scenarios used in the approach for stock assessment, for both the large lakes (via landings and fishing mortality, chapter 3) and for all other water bodies (via survey data scaled to wetted areas, chapter 4).

Scenario	Large lakes		Other waters	
	Fishing mortality 2005-2007	Fishing mortality 2008-2013	Catch efficiency	Density offshore compared to inshore
1/B	0.515	0.22	66%	33%
2/B	0.515	0.22	20%	50%
3/A	0.49	0.15	20%	66%

In addition to providing estimates for the standing stock in 2011-2013, this chapter also provides estimates for different time periods to aid the evaluation of management plans through time. As mentioned in Chapter 4 (section 4.2 and 4.3), not enough data was available for all regions in all periods (*Table 5.2*). Extrapolation between periods is therefore necessary. Extrapolation is needed for the Volkerak-Zoommeer and Zandmaas, the Veluwerandmeren, ditches and the other regionally managed waters (table 5.2). The method of extrapolation for these five types of water bodies is discussed in the next section.

Table 5.2 Eel biomass estimate availability per period and per water body.'-' indicates not sufficient data available.

<table>
<tr><th></th><th></th><th>2005-2007</th><th>2008-2010</th><th>2011-2013</th><th>All years together</th></tr>
<tr><td rowspan="2">Large lakes</td><td>Veluwerandmeren</td><td>-</td><td>-</td><td>Avail</td><td></td></tr>
<tr><td>Other</td><td>Avail</td><td>Avail</td><td>Avail</td><td></td></tr>
<tr><td rowspan="2">Regionally managed waters</td><td>Ditches</td><td>-</td><td>-</td><td>Avail</td><td></td></tr>
<tr><td>Other</td><td>-</td><td>-</td><td>-</td><td>Avail</td></tr>
<tr><td rowspan="3">Nationally managed waters</td><td>Volkerak-Zoom</td><td>-</td><td>Avail</td><td>-</td><td></td></tr>
<tr><td>Zandmaas</td><td>-</td><td>Avail</td><td>Avail</td><td></td></tr>
<tr><td>Other</td><td>Avail</td><td>Avail</td><td>Avail</td><td></td></tr>
</table>

Extrapolation between periods

Extrapolation in this report was done differently than in Bierman et al. (2012). In Bierman et al. (2012) a general annual decrease of 10%, based on the trend in glass eel, of the biomass estimate was used to obtain the biomass estimate for earlier periods. Here the extrapolation from one period (with data available) to another (for which no data were available) was based on known estimates and then used for other water bodies.

For the Veluwerandmeren, sufficient landings data was only available for the period 2011-2013. Because these lakes have an open connection to Lake IJsselmeer and Lake Markermeer, the extrapolation to the other periods was based on the ratio of biomass estimates between periods of these two neighbouring lakes (*Table 5.3*).

For the ditches only survey data in 2011-2013 was available. The estimates for 2011-2013 were therefor also used for the other two periods. For the other regionally managed water bodies survey data were available for the years 2006 up to 2013 yet the spatial-temporal resolution was such that no estimate for separate periods could be done. The density estimate for all years combined was used as estimate of the standing stock for all three periods.

In the nationally managed waters no survey data were available for Zandmaas in the periods 2005-2007. The average of the estimates of 2008-2010 and 2011-2013 was therefor used for this prior period. Volkerak-Zoommeer was only sampled in the period 2008-2010. The estimates for 2008-2010 were therefor used for all three periods. For the other nationally managed water bodies estimates for the three periods are available and no extrapolation is needed.

The biomass estimates for eel larger than 30 cm in scenario 2/B is given in Table 5.23 and the extrapolated data for all periods is then given in Table 5.34. For the regions with data for all periods (IJssel-/Markermeer, Grevelingenmeer and 'other' nationally managed water bodies) an change in biomass through time for the standing stock estimate can then be examined. IJssel-/Markermeer shows an increase in estimated biomass, from 359 tonne om 2005-2007 to 534 tonne in 2011-2013, while a decrease in the estimates can be seen for Grevelingenmeer (73 to 37 tonne) and most nationally managed rivers (501 to 454 tonne). Overall there is no trend in eel biomass over the three periods for all eel > 30cm.

Table 5.3 Extrapolation of estimates for biomass of all eel >30cm (yellow and silver eel combined, in tonnes) in scenario 2/B. In bold the extrapolated estimates.

		2005-2007	2008-2010	2011-2013
Large lakes	IJssel-/Markermeer	443	645	659
	Grevelingenmeer	88	76	37
	Veluwerandmeren	**31**	**44**	45
Regionally managed waters	Ditches	**1268**	**1268**	1268
	Other	**2394**	**2394**	**2394**
Nationally managed water bodies	Volkerak-Zoommeer	**498**	498	**498**
	Zandmaas	**98**	106	90
	Other	501	486	454
	Total	5321	5517	5445

5.2 National stock biomass overview

For each scenario, and both for eel >30 cm and silver eel the available data were extrapolated in order to obtain values for all periods. By subtracting silver eel biomass from the biomass estimate for all eel larger 30 cm, the yellow eel biomass (> 30 cm) is calculated. The yellow eel biomass and the silver eel biomass are used in the calculations for the estimates of key stock indicators (Chapter 7). An overview of the total national stock biomass estimates for the different scenarios and time periods is given in *Table 5.4*.

Table 5.4 Total stock biomass estimates for yellow eel and silver eel (> 30cm) for each period and each scenario in tonnes. The scenarios 1-3 are based on catch efficiency and habitat preference (Chapter 3), while A and B refer to the fitted fishing mortality from the demographic model (Chapter 2).

	2005-2007	2008-2010	2011-2013
Yellow eel >30cm			
Scenario 1/B	1140	1279	1266
Scenario 2/B	3971	4093	4051
Scenario 3/A	4849	5162	5120
Silver eel >30cm			
Scenario 1/B	506	577	550
Scenario 2/B	1349	1425	1393
Scenario 3/A	1625	1847	1804

6. Mortality during silver eel migration due to barriers

Since the report in 2012 changes have been made to improve silver eel migration to the sea. An inventory was held among water boards to update the information on barrier specifics conserving migration (Kroes et al. 2015). In addition, the list of pump types was updated for those barriers that are in WFD waters.

In this chapter we describe the methodology and data on which estimates of barrier mortality are based. The mortality during silver eel migration is one of the sources of mortalities which are used in the overall assessment presented in Chapter 7 (see the flow diagram of the stock assessment in *Figure 6.1*).

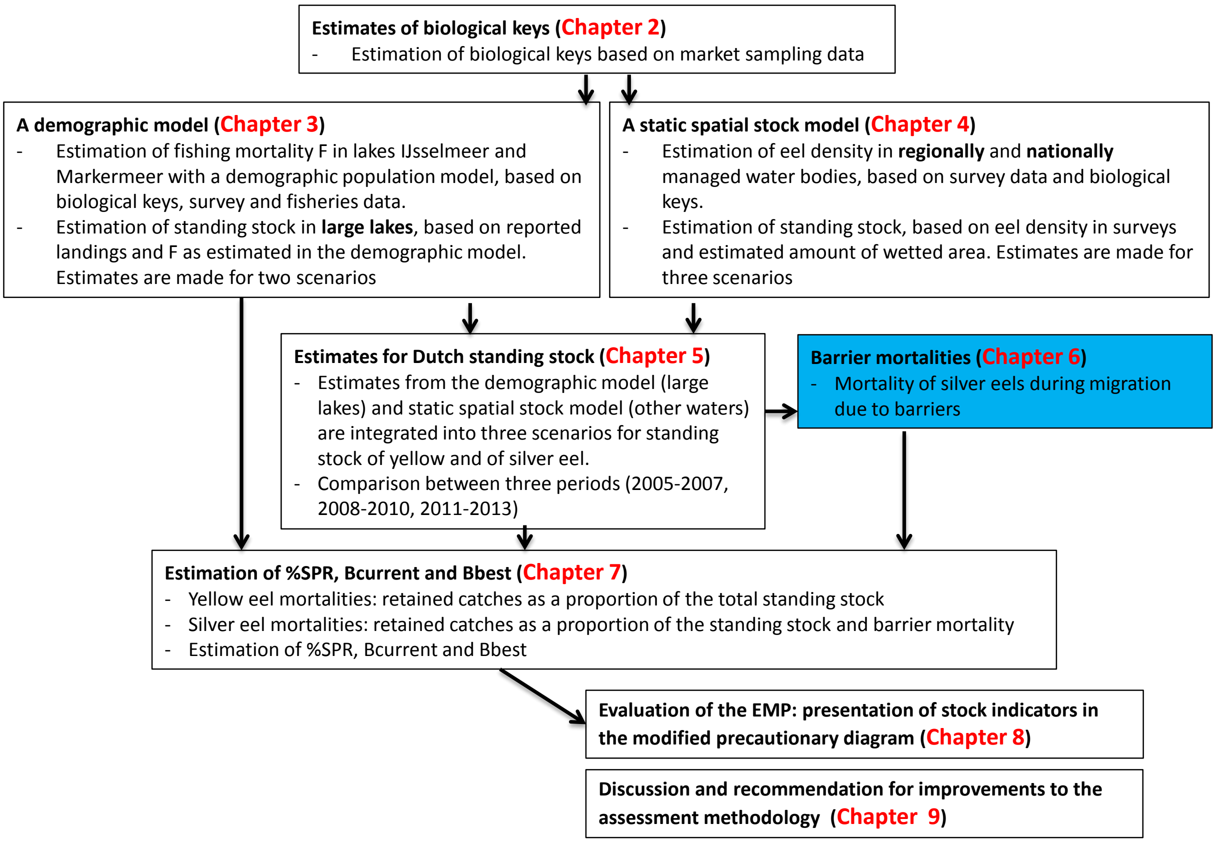

Figure 6.1 Flow chart of the assessment procedure.

6.1 Model for estimating barrier mortality

The Netherlands consists of a complex network of interlinked large and small water bodies, most of which contain eel. There are thousands of pumping stations and even more other potential barriers that could cause mortalities for silver eels during their migration to the sea.
To construct a model for estimating the mortalities of silver eels caused by these barriers knowledge on the following key processes is necessary:

1) Mortalities that eels experience during passage of barriers
2) The biomass of silver eels produced in different inland water bodies, that give the starting positions of silver eels.

3) Routes of silver eels from inland water bodies to the sea, and the barriers eels have to pass on these routes

A conceptual model for silver eel migration is constructed, based on a hierarchy of water bodies, which provide a description of silver eel migration in the Netherlands (*Figure 6.2*). In this conceptual model, silver eels are split into three main groups, according to water body type. Three main types of water body are distinguished, corresponding to the three main hierarchy levels of water bodies in the Netherlands:

1. 1st hierarchy (termed 'polder' water bodies): water bodies which are below sea level and serviced by a large number of small pumping stations with typically high levels of mortality during passage. In the model, each polder is serviced by a single pumping station (i.e. no pumping stations in sequence). Pumping stations of coastal polders can pump water directly into the sea, causing silver eels to 'escape' if they survive the passage. However, for most polders, pumping stations would discharge water into a water body of the 2nd hierarchy in our model ('boezem' water bodies). In the model, polder waters are represented by the wetted area of drainage ditches (Chapter 3; 4.2 Regionally managed water bodies).
2. 2nd hierarchy (termed 'boezem' water bodies): water bodies such as canals, small inland lakes (such as the Frysian lakes), but also smaller streams and rivers which are either connected directly to the sea or to large nationally managed water bodies (the 3rd hierarchy of water body in the model; see below) via larger pumping stations and/or sluices. In the model, boezem waters are represented by all regionally managed WFD water bodies (chapter 3; 4.2 Regionally managed water bodies).
3. 3rd hierarchy (termed 'national' water bodies): large nationally managed water bodies such as sections of the main rivers Rhine and Meuse (including downstream parts) (Chapter 3), the lakes IJsselmeer and Markermeer, Veluwerandmeren and Grevelingenmeer (Chapter 3). Silver eels have been found to experience low levels of mortalities during passage of barriers (if any) in these large water bodies, with the exception of the passage of hydropower plants for eels which start their migration from upstream sections of the main rivers. Yet a large amount of eel biomass passes these barriers.

A visual representation of the framework of the model for migration routes is given in *Figure 6.2*. The hierarchies of inland water bodies (and sections of rivers upstream of hydropower plants) are connected with each other and with the sea as represented by arrows. The model will be completed by:
1) estimation of transition rates between types of water bodies
2) estimation of mortality rates during passage between types of water bodies
Given the starting biomasses of silver eels in the different hierarchies of water bodies, and given estimates of transition and mortality rates, the model can be used to obtain a prediction of the total silver eel mortality during migration to the sea.

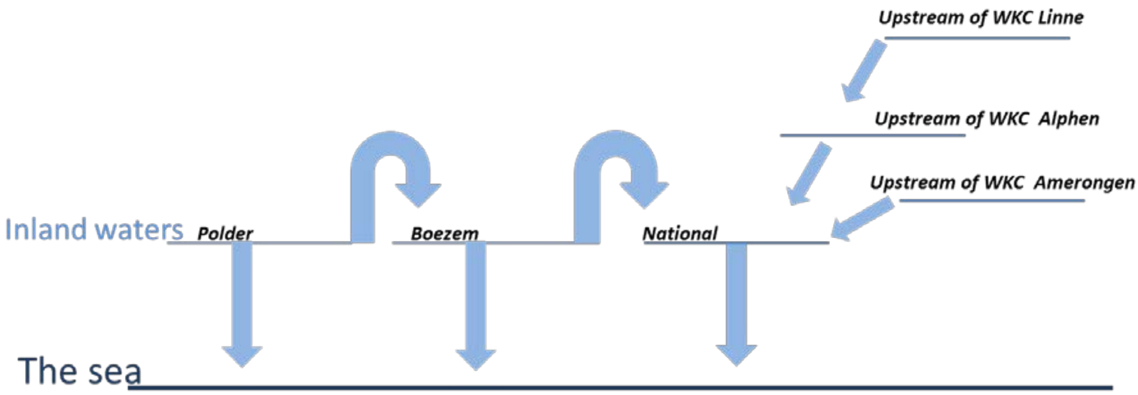

Figure 6.2 A conceptual model for estimating mortality during silver eel migration due to barriers (see text).

A key assumption in this model is that barriers within a hierarchical class, for example within polder waters, are never in sequence. Instead, sequential barrier mortality only occurs if silver eels are transferred from one hierarchical class to another, for example from polder to boezem. This approximation is thought to hold true in the majority of cases. However, there are some polder waters with two boezem layers, in which polder waters are pumped into an 'inner boezem' and subsequently pumped into an 'outer boezem' (which would be the second hierarchy in the model presented here), such as in the polder 'Berkel' (http://www.hhdelfland.nl/projecten/bergboezem-berkel/aanleiding-en-aanpak). We note that, given mortality and transition rates, the percentage of silver eels (out of the total starting biomass) that is estimated to die during migration is dependent only on the proportional allocation of silver eel biomass over the different hierarchies of water bodies. Instead, the biomass of silver eels that are estimated to die during migration will be dependent on the absolute starting biomass. In the overall assessment presented in Chapter 7, only an estimate of the percentage mortality is necessary as a parameter in the estimation of lifetime anthropogenic mortality, or %SPR. Therefore, in this chapter we only illustrate the model with biomass estimates from scenario 2. The differences in the proportional allocation of silver eels between the hierarchies of water bodies are small between the scenarios.
The estimated total production of silver eel in the three hierarchical types of water bodies are given in *Table 6.1*. These estimates are based on the static spatial population model as presented in Chapter 4.

Table 6.1 Estimates of silver eel biomass starting from each of the three hierarchical types of water bodies that are distinguished in the conceptual migration model: 'Polder water' (300 km^2 of ditches) 'Boezem waters' (all the regionally managed water bodies without Veluwerandmeren and Lauwersmeer), and 'national waters' (large nationally managed water bodies such as the main rivers and lakes IJsselmeer and Markermeer). See main text for a description of these three types of water bodies. Estimates are provided as metric tonnes for scenario 2 for the three periods.

	Period		
	05-07	**08-10**	**11-13**
Polder	304	304	304
Boezem	583	583	583
National	462	538	506
Total	**1349**	**1425**	**1393**

General approach to assess mortality rates at barriers

We note that in the parameterisation of the barrier mortality model we use “net mortality rates” for barriers: the proportion of silver eels that ends up in that barrier multiplied by the proportion that dies during passage. In case an alternative route for migration is available, such as a ship lock or sluice in combination with a pumping station, estimates of net mortality rates are typically lower than the proportion of silver eels that die attempting to pass the barrier. This is illustrated in Figure 6.3, for silver eel mortality during passage of a ‘complex’ barrier with a pumping station, ship lock and discharge sluice. The width of the grey bar in Figure 6.3 is proportional to the number of silver eels migrating, with the direction of migration indicated by the arrows. A proportion of the eels may use the route to the ship lock. The remaining silver eels will swim in the direction of the pumping station/discharge sluice, and a proportion of these individuals may choose the ship lock. Out of the remaining silver eels that continue to swim towards the pumping station, a proportion may choose to turn around because of cues caused by the pumping station. This may eventually lead to only a small proportion of eels actually passing the pumping station. This small proportions is multiplied by the mortality rate of the pumping station to obtain an estimate of its net mortality rate.

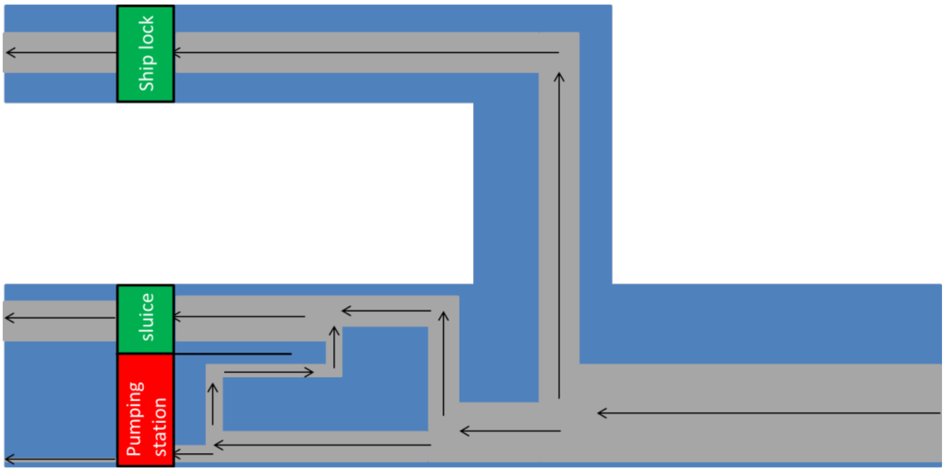

Figure 6.3 An illustration of how net mortality rates are expressed in the barrier mortality model. Barriers may be complex and consist of a combination of pumping stations, ship locks, sluices or other alternative routes for migration (see text). The width of the grey bar is proportional to the number of silver eels migrating via the different routes, with the direction of migration indicated by the arrows.

Estimated mortality rates and transition from polder to boezem or the sea.

Silver eel migrating from the polders to the boezem waters will encounter pumping stations. There are direct and indirect effects of pumping stations on migrating silver eel. In the first place pumping stations can cause damage and direct or delayed mortality in eel when passing through a pump. Secondly, a pumping station may function as a barrier for eel, both during upstream and downstream migration. However, a recent study demonstrated that for migrating silver eel, pumping stations delayed migration but did not function as a permanent barrier as long as the pumping stations are running at some point in time (van Keeken et al., 2013). Thirdly, pumping stations will increase the predation risk of fish. Damaged and confused fish will be easier to prey on by piscivorous fish or birds. But also the risk of being captured by commercial or recreational fishermen is higher around pumping station when migratory fish aggregate while searching for an opportunity to pass. Here, however, we will only focus on the impact of pumping stations on the survival of migrating silver eel when they actually pass through a pumping station.

Pumping stations can roughly be divided in three groups: 1) water wheels, 2) Archimedes screws, and 3) pumps [centrifugal pumps (radial water flow); propeller-centrifugal pumps (radial/axial water flow), propeller pumps (axial water flow)].

Figure *6.4* provides an overview of the distribution of different types of pumping station in the Netherlands (based on a sample of 2813 pumping stations).

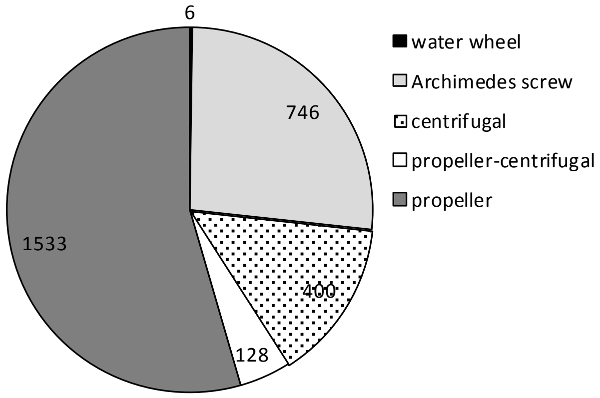

Figure 6.4 Distribution of different types of pumping stations in the Netherlands (redrawn from Kunst et al., 2008).

Appendix B provides an overview of studies conducted mainly in the Netherlands and Belgium on the impact of different types of pumping stations on the survival of eel. These studies clearly demonstrated that in general propeller pumps with axial or axial/radial water flow caused the highest mortality rates when eel passes through these types of pumps. Unfortunately, at least in the Netherlands, these type of propeller pumps are the most common type used to regulate water levels. On a “fish friendliness” scale propeller pumps are in general regarded as “unfriendly” while water wheels and Archimedes screws are relatively “friendly”.

In one study physically undamaged eels were dissected and it was concluded that many of these eels had internal injuries which would result in delayed mortality (Kruitwagen & Klinge, 2008a). In Table 6.2 we defined mortality as the percentage dead eel plus half of the percentage damaged eel. The average silver eel mortality during passage of pumping stations was estimated as the average of the mortalities for each type of pumping station weighted by its occurrence (Table 6.2).

Table 6.2 Calculation of the average pumping station mortality used to estimate silver eel mortality during migration (see also Appendix B).

Pump type	**Proportion (Figure 6.4)**	**Average mortality* (%) (Appendix B)**	**Weighted Mortality (%)**
Water wheel	0.002	0	0
Archimedes screw	0.27	12	3.2
Centrifugal pump	0.14	12	1.8
Propeller-centrifugal pump	0.05	9	0.4
Propeller pump	0.55	56	29.3
PUMP MORTALITY YELLOW EEL MODEL			~35%

* Mortality is % dead + 0.5 of the % damaged.

Extrapolation to Silver eel migration
From polder waters to boezem waters or from polder waters to the sea or: a best guess estimate of 35% mortality, based on a meta-analysis of estimates from a large number of studies, as presented in the paragraph above and Appendix B.

To complete the model, transition rates between the three hierarchies of water bodies (and the sections of river upstream of the hydropower plants are needed. The majority of polders (except some coastal polders) are thought to have pumping stations that discharge water into the boezem rather than the sea. We estimated (best guess) that 20% of the eel in polder waters is transferred directly from polder to sea, whereas the remainder (80%) is transferred to boezem waters where additional mortality due to barrier passage might occur (Figure 6.6).

Estimated mortality rates and transition from boezem to national waters or the sea

The mortality estimates for silver eel migrating from boezem to national waters are based on an inventory of the main migration barriers for silver eel migrating from the Netherlands from Winter et al. (2013a, 2013b). In this study an up to date overview was made of possible barriers, e.g. ship locks, discharge sluices, hydropower stations, weirs and pumping stations where often a combination of these man-made structures are present at sites, for silver eel migration. A list of the 73 main potential barriers was primarily based on size the catchment area that discharges via the potential barrier. To prioritize these potential barriers, the potential biomass of silver eel estimated on densities and area of the waters in the catchment area that discharges via the barriers was used in combination with an assessment of the mortality rates at the potential barrier. In the current evaluation study we used the estimated overall mortality rates per site (often a combination of different types of man-made structures) as listed in these studies (Winter et al. 2013a, 2013b). For each of these barriers it is know if passage leads directly to the sea or to national waters, hence the distribution can be calculated. The information provided by Winter et al. (2013a) allows for mortality and distribution estimates weighted by the silver eel biomass at the barrier as a fraction of total silver eel biomass.

Given the mortalities of barriers weighted by the amount of silver eel per barrier relative to the total amount of silver eel, the overall estimated mortality is 6% for passage to the sea and 17% for passage to national waters. Due to more recent management adjustments, e.g. replacement of fish unfriendly pumps by more fish friendly pumps at some locations (see Appendix C), the mortality for passage from the boezem to the national waters was estimated at 14% for the period 2011-2013. The distribution of silver eel approaching barriers to sea or to national waters was 37% to sea and 63% to national waters, also weighted by silver eel biomass.

Estimated mortality rates from national to sea, and hydropower stations

The approach for barrier mortality estimation for national waters is also based on the inventory of the main migration barriers for silver eel migrating from the Netherlands from Winter et al. (2013a, 2013b) as described above for the barriers in boezem waters.

For the locations of the two largest hydropower stations, that are both situated in the River Vecht, recent data were included to estimate developments in mortality rates. The river Meuse, originating in France and flowing through Belgium and the Netherlands, has a total length of 935 km, a catchment area of 36,000 km3 and a mean discharge of 230 m^3/s, characterized by short peaks flows following rainfall (Winter et al. 2006). Five weirs and two Hydro Power Station (HPS)–weir complexes are located in the Dutch section of the river Meuse. Fishways and shiplocks are located alongside each weir and each HPS–weir complex. In 2002, 2004, 2010, 2011 and 2013, 750 silver eel (150 each year) were used for a telemetry study using the Nedap TrailTM system (NEDAP, Groenlo, the Netherlands). For this system an extensive infrastructure is available in the Dutch rivers (Breukelaar et al. 1998). Fish were caught by a local professional fisherman with fyke nets during September and October in the River Meuse at Ohé en Laak. Eels with completely silvery white ventral side were used, rejecting individuals with yellow or partly yellow ventral sides. In the study eel larger than 50 cm were used and all individual eel were assumed to be females since males do not grow larger than 50 cm (Dekker 2000). The surgical procedure as described by Winter et al. (2006) was used for all eel.

Fyke fisheries was prohibited in the months September, October and November in 2010 and completely prohibited after April 1st 2011. Comparing the telemetry studies before and after 2010, no increase was found in successful passage of eel to the North Sea after the closure of the fisheries (Table 6.3). Since mid-November 2011 an adapted turbine management regime was implemented that on forehand was expected to reduce eel mortality from 24% (Bruijs et al. 2003) to 18% (reduction of up to 24-25%, pers com. H. Bakker RWS). This was implemented on 17 November 2011 at HPS Alphen/Lith and 21 November 2011 HPS Linne in the Meuse and 17 November 2011 at HPS Amerongen in the Lower Rhine. The telemetry data of the river Meuse in 2010 (no adapted regime) at HPS Linne and 2013 (adapted regime) were compared to see whether there is an indication for mortality reduction. This analysis was done in two ways: 1) Eel that passed the HPS at Linne and were not detected at the following detection covering the full river bed ('Linne Dorp', station nr 8 Figure 6.5) were classified as disappeared. 2) Eel that passed the HPS at Linne (see Figure 6.5) and were not detected after Linne Dorp were classified as mortality, although the possibility that eel remained alive and stationary between these detection station for the entire period of the battery life of 2 year transponder cannot be ruled out, but is considered to be unlikely compared to suffering mortality.

1) 2010: 84 HPS passage, 73 detected at Linne Dorp = 13% mortality
   2013: 94 HPS passage, 83 detected at Linne Dorp = 12% mortality
2) 2010: 84 HPS passage, 69 eel detected after Linne Dorp = 18% mortality
   2013: 94 HPS passage, 73 eel detected after Linne Dorp = 22% mortality

Thus the telemetry data show no indication for an improvement of mortality reduction at HPS Linne when comparing 2010 and 2013 data. However, environmental conditions during passage such as discharge can affect mortality rates and cause variation in mortality rates between periods and years. The mortality rate at the hydropower plants was not directly measured and therefore these telemetry data only give a first indication whether reduced mortality did occur. Direct mortality measurements as Bruijs et al. (2003) should be done to evaluate the adapted management for mortality reduction of migrating silver eel more accurately.

Table 6.3 Observed and estimated, i.e. corrected for misdetection rates, mortality rates of silver eel in the river Meuse (Winter et al. 2006, - 2007, Jansen et al. 2007, Griffioen et al. 2013 and Griffioen & Winter unpublished results).

	2002 (n=121)		2004 (n=105)		2010 (n = 121)		2011 (n=88)		2013 (n = 110)	
	Obs (%)	Est (%)	Obs (%)	Est (%)	Obs (%)	Est (%)	Obs (%)	Est (%)	Obs (%)	Est (%)
successful passage to sea cf. Winter et al. (2006) *	37	>37	31	>31	30	>30	18	>18	20	>20
commercial fisheries	15	15-21	13	19-22	0	0	0	0	0	0
recreational fisheries	1	1	2	3	0	unknown	0	unknown	0	unknown
hydropower Plant mortality cf Winter et al. (2006)		16-26		25-34		15-26		13-23		19-27
hydropower Plant mortality cf Griffioen et al. (2013)	NA	NA	NA	NA		22-25		25-27		30-31
"unknown" mortality/disappearance	38	15-31	35	10-22		44-55		59-69		53-61

*not included possible mortality between the last detection station and the sea in Nieuwe Waterweg (~20km).

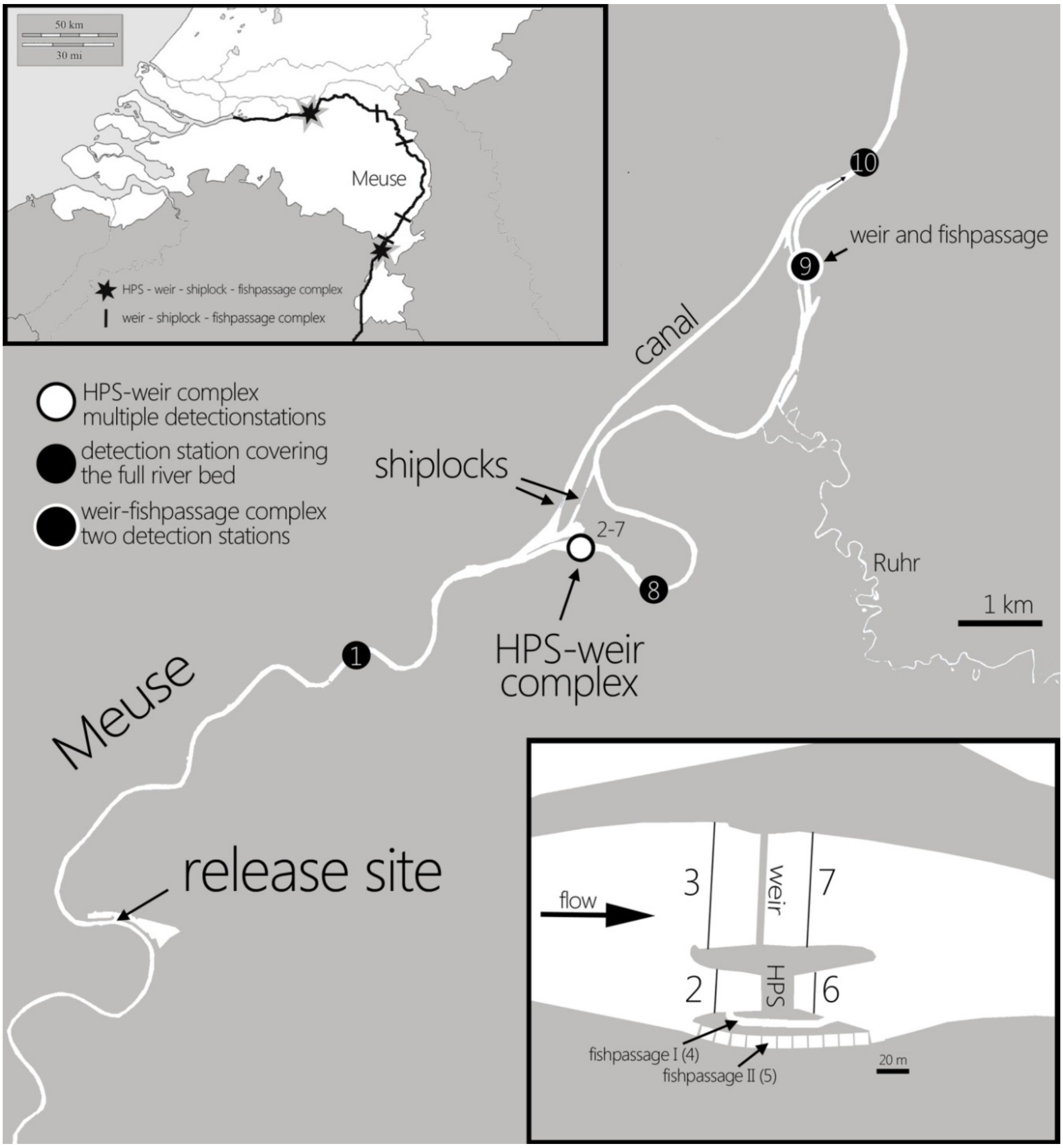

Figure 6.5 Overview of the study location: a 15 km part of the river Meuse with ten detection stations and two parallel canals accessible by ship locks. Bottom right a graphical representation of the HPS – weir complex is given with six detection stations (detection stations two – seven). Details of lakes and canals in the vicinity of the river are not shown in the figure.

Given the mortalities of barriers weighted by the amount of silver eel per barrier relative to the total amount of silver eel, the overall estimated mortality from national waters to the sea (excluding hydropower stations) is 0.9%. Silver eels in the sections of river upstream of the hydropower plants are estimated to all (100%) pass through these barriers during their downstream migration to the sea and suffer from mortality. It is assumed that silver eel that passes the hydropower stations enters the national waters (minus the mortality loss) and suffers from the migration mortality from the national waters to the sea. However, silver eel passing Linne will also pass Alphen as both hydropower stations are in the River Meuse.

6.2 Migration mortality

Based on the distribution and mortality estimates given above the model scheme can be filled with a best guess mortality scenario. This scenario is illustrated in Figure 6.6.

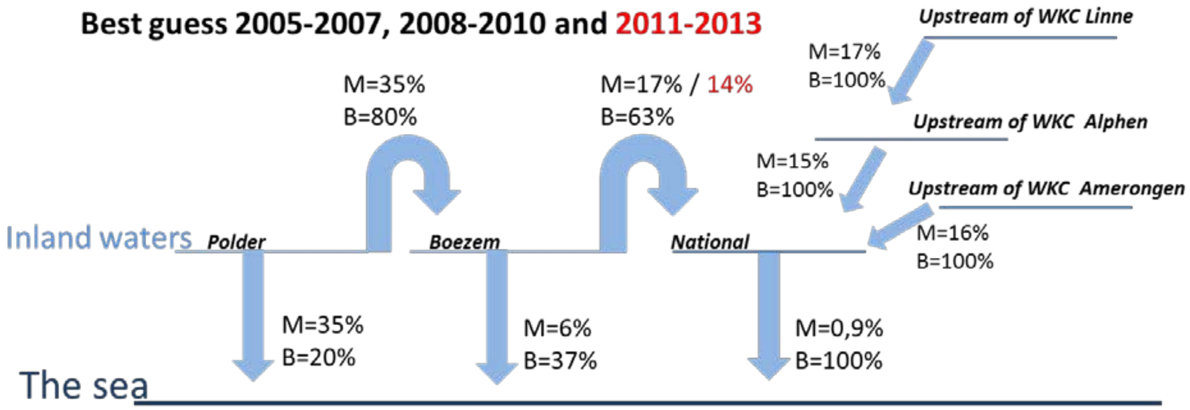

Figure 6.6 Migration mortality scheme, including mortality estimates and transition rates, used to estimate migration mortality of silver eel. The percentage in red is for the period 2011-2013.

Based on Figure 6.6, the estimated losses of silver eel through migration mortality are given in Table 6.4. Recent trap and transfer initiatives, in which silver eel is caught above a barrier and 'lifted' across it, are taken into account when calculating the overall migration mortality for silver eel. Since 2011 several (pilot)projects have started at migration barriers (pumping stations) to assist the migration of silver eel. In 2011 0.54 tonne of silver eel was caught and released again past barriers at four sites ('assisted migration'). In 2012 this amount increased almost tenfold to 4.80 tonne (15 sites), and in 2013 to 9.32 tonne (25 sites). However, the mortality rates of silver eel passing the selected barriers has been assessed at moderate to low (Bierman *et al.* 2012; Winter *et al.* 2013a). Thus, the net amount of eels saved by the assisted migration is much lower than the amount caught and released. In 2013 the barriers for silver eel were prioritised (Winter *et al.* 2013a) to improve the selection and efficiency of assisted migration initiatives. Applying location-specific mortality rates, the net amount of 'saved' eels was 0.13 tonne in 2011, 0.9 tonne in 2012 and 2.29 tonne in 2013, a five-fold (2012) to six-fold increase (2013) compared to 2011 (de Graaf & Deerenberg 2015). In the overall mortality estimate the average of 1.1 tonnes was used for the period 2011-2013.

Table 6.4 Estimated losses of silver eel in hydropower plants, pumping stations, sluices and other barriers. Estimates are given as metric tonnes (absolute values are valid only for estimates produced under scenario 2), and as percentages of the total starting population of silver eel (valid for all scenarios). See Figure 6.66 for mortality rates which have been used.

	Estimate 05-07	Estimate 08-10	Estimate 11-13
Leaving polder waters	106	106	106
Leaving boezem waters	96	96	82
Hydropower plants	7	17	12
Major national waters (other than hydropower plants)	8	8	8
Trap-and-transfer	0	0	-1.1
Total	**217**	**227**	**207**
% mortality from total silver eel biomass in inland waters	16%	16%	15%

The overall percentage migration mortality is then the sum of losses (Table 6.4) divided by the total silver eel biomass (Chapter 3; Chapter 5.2). Estimates are made separately for the period 2011-2013 as mitigation measures were taken (see also Appendix C).

We note that the mortality estimates in hydropower plants in are likely to be underestimates, because these include only silver eels produced in Dutch sections of the main rivers. However, for the period 2011-2013 an estimated 149 tonnes of silver eel migrate downstream on the river Rhine from Germany (pers. comm. Karin Camara), and 16.2 tonnes of silver eel migrate downstream on the river Meuse from Belgium and Germany. The proportion of silver eel migrating down the Rhine river from Germany passing the river section of the Amerongen hydropower plant is estimated to be 6% (Klein-Breteler et. al. 2007). Using this estimate, the mortality on these eels migrating from Germany is estimate at 149*0.06*0.16=1.3 tonnes (16% mortality during passage Amerongen; Figure 6.6). The additional 16.2 tonnes of silver eel in the Meuse river is expected to pass the hydropower plants at Linne and Alphen, causing an additional 16.2*0.17 + (1-0.17)*16.2*0.15 = 4.8 tonnes of silver eel mortality. The silver eel mortalities on these ‘foreign’ eels migrating from Germany and are not taken into account in the evaluation of the Dutch EMP.

6.3 Discussion

In comparison to the model approach used for the 2012 evaluation study of the Dutch Evaluation Plan for 2009-2011 (Bierman et al. 2012), the current approach relies less on overall average estimates. Given the large number of polders and lack of site-specific data for most of these sites, for assessing the polder waters a ‘bottom up’ approach is not feasible at this stage and therefore mortality rates are based on overall silver eel production estimates combined with an overall calculated average mortality rate. For the boezem and national waters, in contrast to the previous 2012 evaluation, in this evaluation a more bottom up approach could be used that uses site specific estimates for mortality rates at specific sites and silver eel production estimates from the catchment area that discharges via the barrier site based on an inventory study from 2013 (Winter et al. 2013a, 2013b). This approach will yield more accurate estimates than the approach based on averages as used in the 2012 evaluation. The quality of the underlying data that was used in the 2013 silver eel barrier assessments is however highly variable and often still incomplete (Winter et al. 2013a). Some sites are very well studied, e.g. the sites with hydropower stations in the River Meuse (Winter et al. 2006, 2007, Jansen et al. 2007, Griffioen et al. 2014), the discharge sluices complexes in Haringvliet (Winter & Bierman 2010) and at the sluices-pumping station complex at IJmuiden (Winter 2011), but for other sites, e.g. ship locks and some pumping station sites, data on relative route passage and mortalities per route at a specific site are still largely lacking. The barrier-mortality model as presented here to estimate mortality of silver eels during migration can be further developed to enable a full ‘bottom up and site-specific data driven’ approach. Several maps and lists of barriers are available (e.g. Kroes et. al. 2008; Buijse et. al. 2009). However, this is to our knowledge the first formal model to estimate mortalities during passage of barriers which takes account of variation in starting positions and migration routes of silver eels. Additionally, we used overall mortality rates for individual barriers which account for alternative routes which silver eels may use (paragraph 6.2).

The model presented here can be used as a blue print for further development and refinement. In particular, the characterisation of water bodies as polder or boezem waters needs to be further evaluated. Also, the assumption that pumping stations are not positioned in sequence within polder or boezem waters needs to be further evaluated. A more realistic spatially explicit ‘bottom up’ model as indicated above could be based upon the methodology described in Bierman et al. (2012, Appendix A) to estimate migration routes. Such a route analysis will provide the best basis for models to compute barrier mortality rates.

7. Estimates of key stock indicators

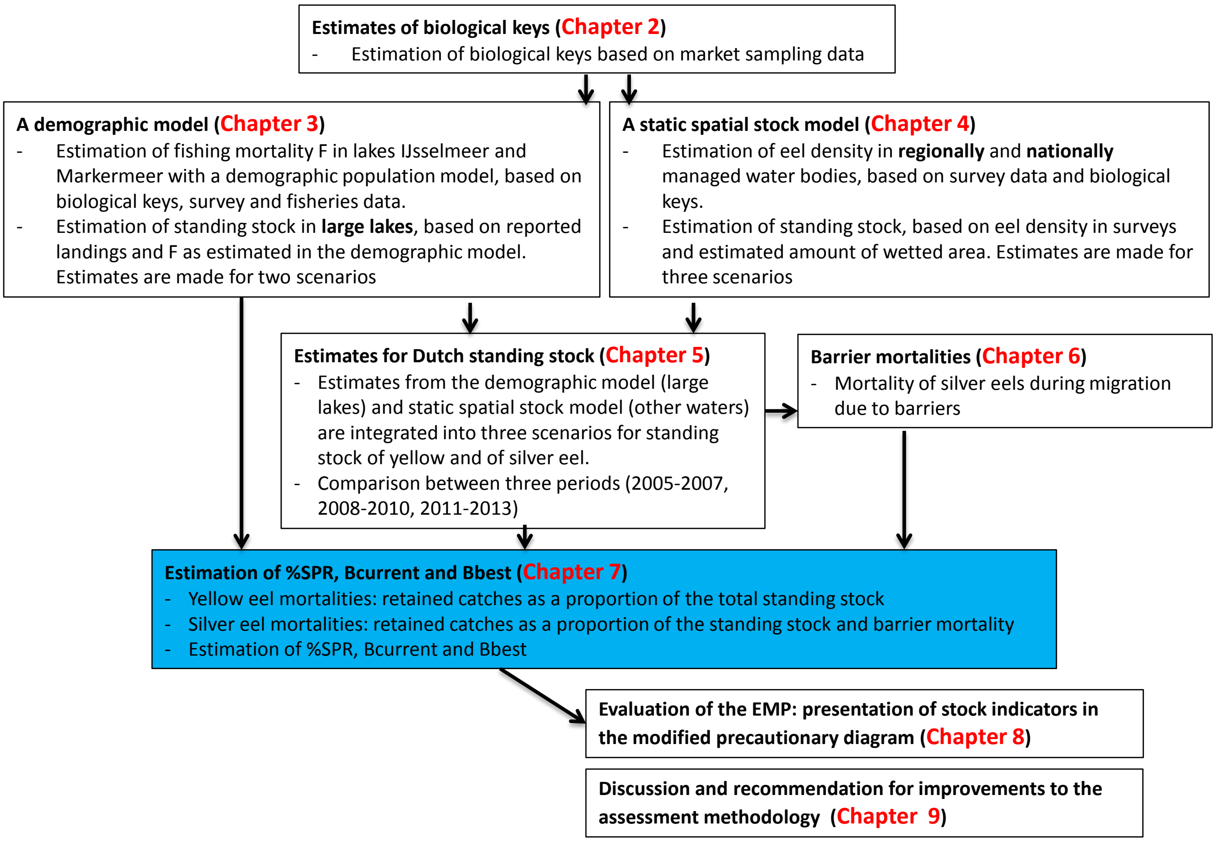

Figure 7.1 Flow chart of the assessment procedure.

To calculate a single estimate of the Lifetime Anthropogenic Mortality (LAM)(ΣA in Table 1.2) for each period the mortalities for yellow eel and silver eel were split into a fishing and a barrier component. The latter is assumed to affect silver eel only. As was explained by in Chapter 1, and in Bierman et al. (2012), LAM can be expressed as %SPR: the spawner per recruit ratio (ICES 2014 and references therein). This ratio can in turn be calculated based on the overall silver eel mortality from fishing and migration (α), and the proportion silver eel production resulting from yellow eel biomass and fishing mortality targeting yellow eel (β) (Figure 7.2). To calculate this β the silver eel production before silver eel mortality from fishing or barriers occurs is estimated for two values of yellow eel fishing mortality. Then β is the estimated silver eel production for $F_{yellow}>0$ divided by the estimated silver eel production for $F_{yellow}=0$ (no fishing mortality). β is hence a measure of the current silver eel production (with current $F_{yellow}>0$) relative to the best possible production in absence of yellow eel fishing mortality ($F_{yellow}=0$).
In this chapter the key stock indicators are estimated based on the results from other chapters as well as additional information on catches.

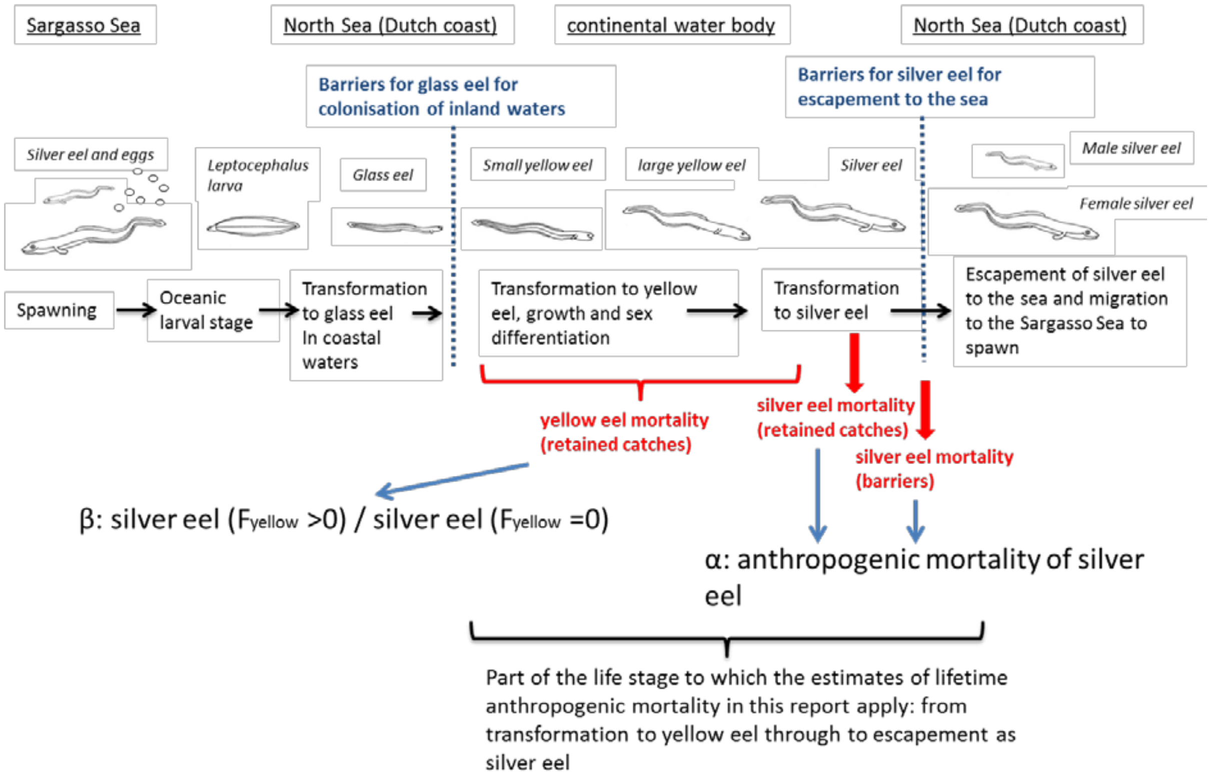

Figure 7.2 The life cycle of a European eel, with the part of the life cycle to which the Dutch Eel Management Plan (EMP) applies and for which 'Lifetime Anthropogenic Mortality' (LAM) rate estimates α and β are made in this report.

7.1 Anthropogenic mortality through fishing and β

Yellow eel

Yellow eel anthropogenic mortality is defined as fishing mortality from both commercial and recreational catches, including mortality from capture and release. Mortality from non-reported catches such as poaching or mortality caused by barriers is not included here.

The estimated mortality ($\hat{F}$) is a function of the proportion of retained catches and the estimated standing stock, following the equation:

$$\hat{F} = -\log_e(1 - (RC/(biomass+RC)))$$

where RC is the retained catch of yellow eel and biomass the biomass of yellow eel > 30 cm, both in tonnes.
We note that with this estimate of fishing mortality, it is assumed that this mortality was instantaneous. Therefore, the effects of natural mortality on stock trends within a year is ignored. However, this approximation seems reasonable for eel because it is such a long lived species and year-on-year trends in biomass are relatively small.

In order to calculated the estimated mortality $\hat{F}$, information on the retained catches is needed from both recreational and commercial fisheries, which includes catches from marine waters. For the period 2005-2007, retained catches of yellow eel by commercial and recreational fishers were estimated at 640 and 200 tonnes by commercial and recreational fishers respectively (Table 7.1). In addition, 280 tonnes of silver eel was caught by commercial fishers (The Ministry of Agriculture, Nature and Food quality, 2009;

Tables 2.3.1 and 2.3.3; with data from Vriese et al. 2007). Released recreational catches were estimated to be 100 tonnes.

For the period 2008-2010 the total of commercial catches for the year 2010 was used, 452 tonnes, as provided by the Ministry of Economic Affairs. The catch was split in to yellow and silver eel based on the length frequency distribution of the marked sampling (2011-2013) for all available years and locations, and the biological keys sex ratio, maturation and the length-weight relationship (Chapter 2). This resulted in an estimate of 56% yellow eel. For the recreational retained and returned catches data from 2010 were used as presented in Van der Hammen et al. (2011) based on marine and freshwater registrations. For the period 2011-2013 the average of the total commercial catches 2011-2013 was used, 344 tonnes, as provided by the Ministry of Economic Affairs. Again this value was split into yellow and silver eel using the 56% from the marked sampling. Data on recreational retained and returned catches were obtained in the year 2012, and presented in Van der Hammen et al. forthcoming.
A mean estimate 12% of Catch and Release mortality was assumed to calculated the losses from returned eel from the recreational fisheries (van der Hammen & de Graaf, 2015). It is assumed that the recreational catches consist only of yellow eel. An overview of estimated retained and released catches by recreational and retained catches by commercial fishers for the three periods is given in *Table 7.1*.

Table 7.1 Overview of fresh water commercial and recreational catches for the three periods in tonnes. The released recreational catches are converted into a loss based on catch-&-release mortality of 12%, the total biomass of released eel by recreational fishers is given in brackets.

	2005-2007		2008-2010		2011-2013	
	Silver eel	Yellow eel	Silver eel	Yellow eel	Silver eel	Yellow eel
Recreational retained	-	200	-	100	-	59
Recreational Released loss (total)	-	12 (100)*	-	21 (175)	-	25 (212)
Commercial	280	640	194	248	151	193
Total	280	852	194	369	151	277

**rough estimate (extrapolation) based on the trend in the ratio between retained/released eel in 2008-2010 and 2011-2013.*

The total yellow and silver eel biomass, for the different periods and scenarios, is presented in table *Table 5.4* (Chapter 5). Based on the function above, stock and catch estimates $\hat{F}$ is calculated for each period and scenario (*Table 7.2*).

Table 7.2 Fishing mortality ($\hat{F}$) estimates for yellow and silver eel, for each scenario and period.

	2005-2007	2008-2010	2011-2013
Yellow eel			
Scenario 1/B	0.56	0.25	0.20
Scenario 2/B	0.19	0.09	0.07
Scenario 3/A	0.16	0.07	0.05
Silver eel			
Scenario 1/B	0.44	0.29	0.24
Scenario 2/B	0.19	0.13	0.10
Scenario 3/A	0.16	0.10	0.08

As a logical result from the different scenario's with different biomass estimates, for each period there is an decreasing $\hat{F}$ with increasing biomass estimate. The fishing mortality estimate decreases from period 2005-2007 to period 2011-2013, for all scenario's as a result from the decrease in commercial and retained recreational catches. The drop in silver eel mortality after 2005-2007 could be explained by the closure of the migration season in 2009, given the reliability of the data at hand.

Parameter β, used in the calculation of %SPR, is the estimated silver eel production for $F_{yellow}>0$ divided by the estimated silver eel production for $F_{yellow}=0$ (no fishing mortality on yellow eel) (with $F_{yellow} > 0$ from *Table 7.3*) (see also Figure 7.2). β is calculated with the demographic model with the change in sex ratio, by estimating the impact of $\hat{F}$ of the yellow eel stock on silver eel production.

Table 7.3 Estimates of β based per period and per scenario.

	2005-2007	2008-2010	2011-2013
Scenario 1/B	5.8	20.6	27.7
Scenario 2/B	28.2	54.6	62.5
Scenario 3/A	34.0	61.3	68.5

7.2 Silver eel anthropogenic mortality estimate, α

Silver eel anthropogenic mortality, α, consist of mortality during migration from freshwater to the sea (Chapter 4) and fishing mortality as presented above (see also Figure 7.2). The mortality is then based on the following function:

$$\frac{\alpha}{100} = 1 - \left({(B_{start} - RC)(1 - M_{barrier})} \middle/ {B_{start}} \right)$$

Where B_{start} is the biomass of silver eel production, 'starting' migration from inland water bodies (before silver eel mortalities have taken place), RC is the estimated retained silver eel catch, and $M_{barrier}$ is the percentage barrier overall mortality.

For each period and scenario the necessary ingredients were calculated: B_{start} in Chapter 5. RC as mentioned above (7.1 Anthropogenic mortality through fishing and β) and $M_{barrier}$ in Chapter 6. With these ingredients and the equation above the values of α were calculated for each scenario and period (*Table 7.4*).

Table 7.4 The estimates of α for the scenario's and periods.

	2005-2007	2008-2010	2011-2013
Scenario 1/B	62.5	44.2	38.2
Scenario 2/B	33.5	27.4	24.1
Scenario 3/A	30.5	24.8	22.0

7.3 Estimated %SPR, Bcurrent and Bbest

The estimated yellow and silver eel mortalities and the subsequent values of α and β can be used to calculate the %SPR, the spawner to recruit ratio. Here, %SPR is defined as the current escapement of silver eel as a percentage of the best possible escapement (if all anthropogenic mortalities were mitigated). %SPR is estimated as:

$$\frac{\%SPR}{100} = \boldsymbol{\beta}\left(\mathbf{1} - {}^{\boldsymbol{\alpha}}/_{\mathbf{100}}\right)$$

An estimate of lifetime anthropogenic mortality is then given by:
LAM = 100 - %SPR
An estimate of the best possible escapement of silver eel (if all anthropogenic mortalities for both yellow and silver eel are reduced to zero), B_{best}, has been made as (again expressed as a percentage):
B_{best} = ($B_{current}$*100)/%SPR
$B_{current}$ is the current escapement, the surviving tonnage of the silver eel stock (B_{start}) after all silver eel anthropogenic mortality (1-α).
All these indicators can be calculated for the different periods and scenarios (*Table 7.5*).

Table 7.5 Overview of all stock indicators per period and per scenario. Yellow eel and silver eel stock estimates refer to eel larger than 30 cm.

2005-2007		**Scenario**		
		1	**2**	**3**
Yellow eel mortality	Yellow eel stock (tonnes)	1140	3971	4849
	Retained catch (tonnes)	852	852	852
	$\hat{F}$	0.56	0.19	0.16
	β	5.8%	28.2%	34.0%
Silver eel mortality	Silver eel stock (tonnes) (B_{start})	506	1349	1625
	Retained catch (tonnes)	280	280	280
	Mortality Barriers	16%	16%	16%
	α	62.5%	33.5%	30.5%
$B_{current}$	Tonnes	189	897	1129
B_{best}	Tonnes	3288	3187	3327
%SPR	% from B_{best} ($B_{current}/B_{best}$)	5.8%	28.1%	33.9%
LAM	100-%SPR	94.2%	71.9%	66.1%

2008-2010		**Scenario**		
		1	**2**	**3**
Yellow eel mortality	Yellow eel stock (tonnes)	1279	4093	5162
	Retained catch (tonnes)	369	369	369
	$\hat{F}$	0.25	0.09	0.07
	β	20.6%	54.6%	61.3%
Silver eel mortality	Silver eel stock (tonnes) (B_{start})	577	1425	1847
	Retained catch (tonnes)	194	194	94
	Mortality Barriers	16%	16%	16%
	α	44.3%	27.4%	24.8%
$B_{current}$	Tonnes	322	1035	1389
B_{best}	Tonnes	1570	1900	2272
%SPR	% from B_{best} ($B_{current}/B_{best}$)	20.5%	54.5%	61.1%
LAM	100-%SPR	79.5%	45.5%	38.9%

2011-2013		**Scenario**		
		1	**2**	**3**
Yellow eel mortality	Yellow eel stock (tonnes)	1266	4051	5120
	Retained catch (tonnes)	277	277	277
	$\hat{F}$	0.20	0.07	0.05
	β	27.7%	62.5%	68.5%
Silver eel mortality	Silver eel stock (tonnes) (B_{start})	550	1393	1804
	Retained catch (tonnes)	151	151	151
	Mortality Barriers	15%	15%	15%
	α	38.3%	24.1%	22.0%
$B_{current}$	Tonnes	340	1057	1407
B_{best}	Tonnes	1232	1697	2058
%SPR	% from B_{best} ($B_{current}/B_{best}$)	27.6%	62.3%	68.4%
LAM	100-%SPR	72.4%	37.7%	31.6%

8. Evaluation of the EMP

In this chapter we evaluated the impact of the eel management plan using the indicators (B_0, B_{best}, $B_{current}$ and LAM for 2005-2007, 2008-2010 and 2011-2013) (*Table 7.5*) and the modified ICES precautionary diagram.

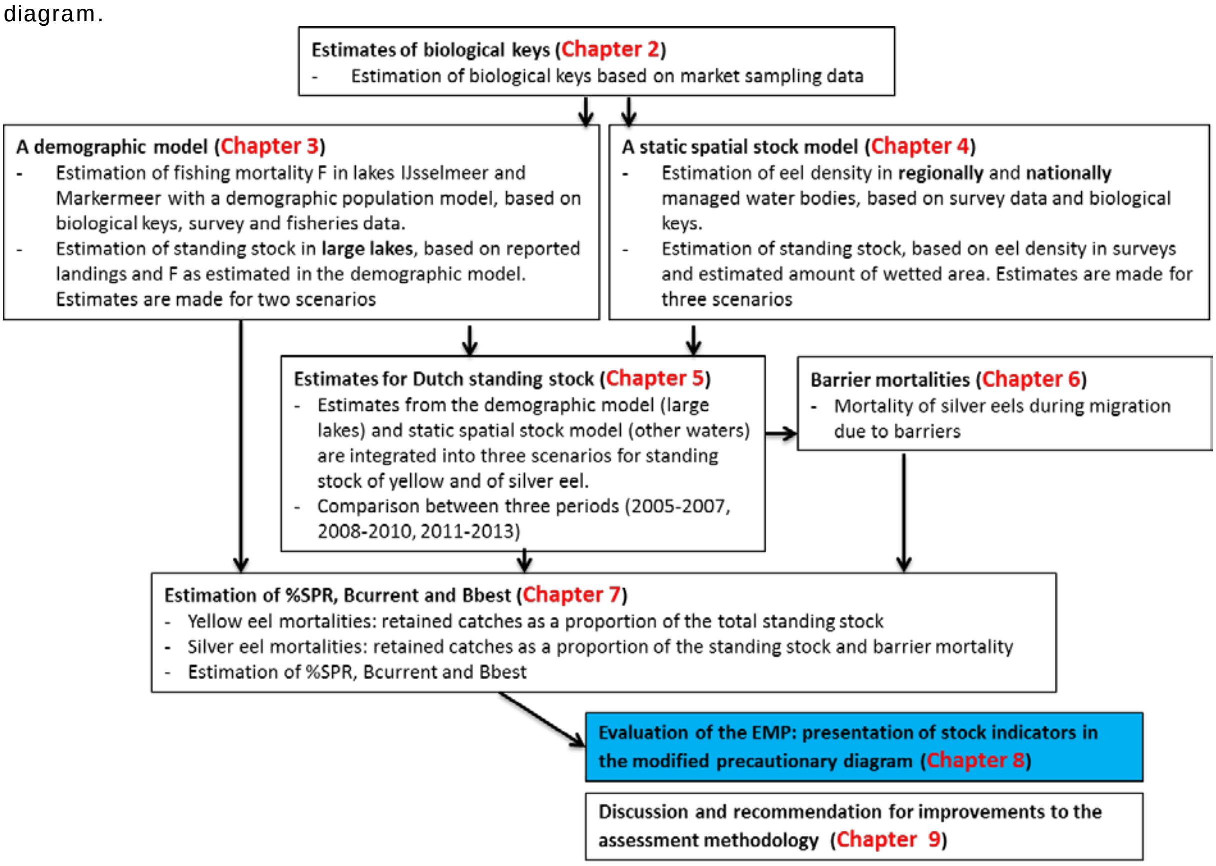

Figure 8.1 Flow chart of the assessment procedure.

8.1 ICES Precautionary Diagram

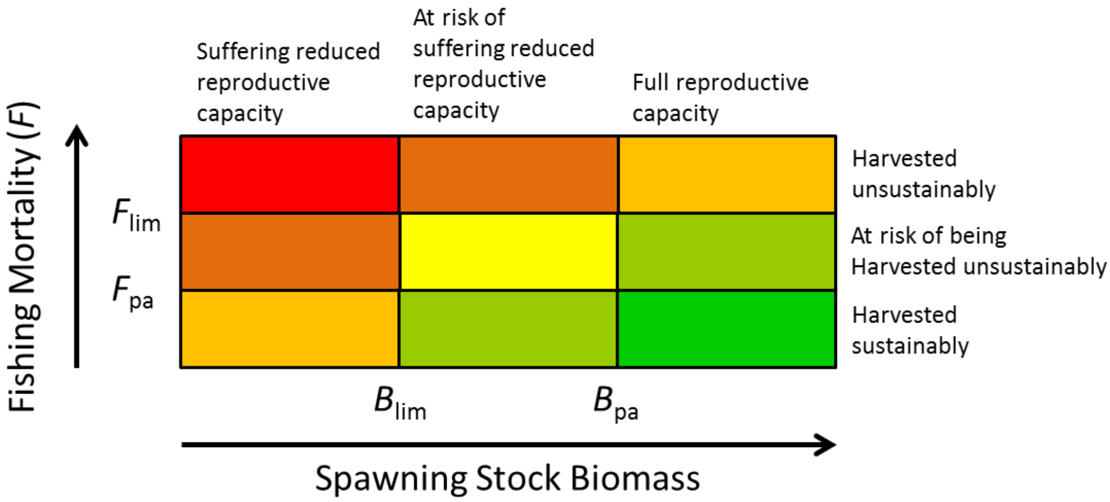

Figure 8.2 Schematic representation of the ICES Precautionary Approach showing the status of a stock in relation to the limit reference points and precautionary reference points (see also Table 8.1).

The conceptualization and handling of uncertainty in advice forms the fundament for successful management of fish stocks such as eel. ICES (2014 and references therein) developed a precautionary approach (PA) framework to address the issues of uncertainty in its advice. The PA framework builds on establishing limit reference points (LRP) reflecting stock states that should be avoided, and precautionary reference points (PRP) reflecting the risk of crossing the LRPs. Both reference points are defined in terms of fishing mortality (*F*) and spawning stock biomass (*B*) (*Figure 8.2*; *Table 8.1*).

Table 8.1 Reference points of the ICES precautionary approach framework (ICES 2009; see also Figure 8.2).

	Spawning stock biomass (SSB)	**Fishing mortality (F)**
LIMIT reference point	B_{lim}: minimum biomass. Below this value recruitment is expected to be 'impaired' or the stock dynamics are unknown.	F_{lim}: exploitation rate that is expected to be associated with stock 'collapse' if maintained over a longer time.
PRECAUTIONARY reference point	B_{pa}: precautionary buffer to avoid that true SSB is at B_{lim} when the perceived SSB is at B_{pa}.	F_{pa}: precautionary buffer to avoid that true fishing mortality is at F_{lim} when the perceived fishing mortality is at F_{pa}.
	The buffer safeguards against natural variability and uncertainty in the assessment. The size of the buffer depends upon the accuracy of the projections (of SSB and F) and the risk society accepts that the true SSB is below B_{lim} and the true F is above F_{lim}. The accuracy of the projections depends on the magnitude of the variability in the natural system and of the accuracy of the population estimates.	

The ICES precautionary approach framework also illustrates the appropriate division between management and science. While it is the responsibility of science to define the limit references points, the decisions on precautionary reference points (i.e. defining acceptable risk levels) lies with "society". The two functions of the reference points therefor create transparency in the separation of responsibilities between scientists and managers, and in the communication of uncertainty in the advice.

8.2 ICES Precautionary Diagram modified for eel

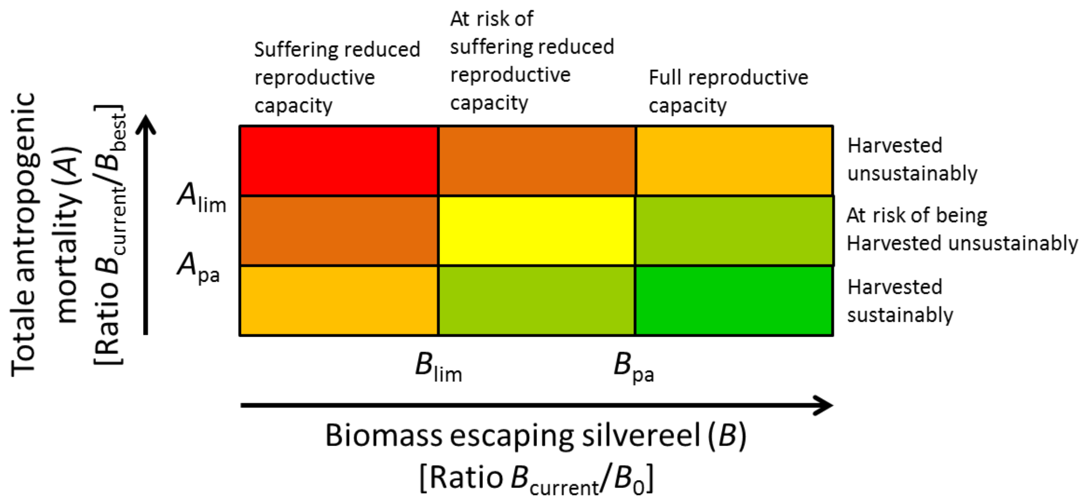

Figure 8.3 The ICES Precautionary Diagram modified for eel. A schematic representation of the status of the eel population (horizontal axis) and the impacts of anthropogenic mortality (vertical axis) in relation to the limit reference points and precautionary reference points.

Over the past years the ICES Study Group on International Post-Evaluation of Eel (SGIPEE) and the ICES Working Group on Eels (WGEEL), have progressively been working on a pragmatic framework for a (inter)national post-evaluation of the status of the eel stock and the effect of management measures (ICES 2014 and references therein).

Firstly ICES (2014 and references therein) derived a framework for deriving stock indicators, based on four estimates:

B_0 The amount of silver eel biomass that would have existed if no anthropogenic influences had impacted the stock.

$B_{current}$ The amount of silver eel biomass that currently (assessment year) escapes to the sea to spawn.

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

ΣA The life time anthropogenic mortality; the fishing (commercial + recreational) mortality rate, summed over the age-groups in the stock, and the reduction effected + the mortality rate outside the fishery (hydropower plants, pumping stations etc.), summed over the age-groups in the stock, and the reduction effected.

In the Dutch Eel Management Plan (Ministry of Economic Affairs, 2009), estimates of pristine biomass (13.000 t) and of current anthropogenic impacts were provided, and thus has set reference points to which the state of the local stock and efficacy of implemented management actions can be compared.

In the second place ICES (2014 and references therein) adapted the classical ICES precautionary diagram to the eel case (*Figure 8.3*). On the horizontal axis “spawning stock biomass” was replaced by “biomass escaping silver eel”. In the modified ICES precautionary diagram the horizontal axis reflects the status of the stock (biomass escaping silver eel, ratio $B_{current}/B_0$) in relation to the estimated pristine situation. On the vertical axis “fishing mortality” has been replaced with “total anthropogenic mortality”, a summation of all (quantified) sources of anthropogenic mortality during the continental phase of eel. The vertical axis indicates to what extend the current population is protected in comparison with a situation where no anthropogenic mortality occurs and the production of silver eel per glass eel is at its maximum (anthropogenic mortality, ratio $B_{current}/B_{best}$). The horizontal axis demonstrates to what extent the status of the eel stock is sustainable while the vertical axis illustrates to what extend the current use and management of the stock are sustainable.

8.3 Reference points ICES Precautionary Diagram modified for eel

With the stock indicators (B_0, B_{best}, $B_{current}$, ΣA) and a pragmatic framework (modified precautionary diagram) in place, the missing (and most difficult) piece of the puzzle remains the quantification of the limit reference points and precautionary reference points.

ICES provides fisheries advice that is consistent with the broad international policy norms of the Maximum Sustainable Yield approach, the precautionary approach, and an ecosystem approach while at the same time responding to the specific needs of the management bodies requesting advice. When information for determining reference points is poor or absent, ICES (2009) advises that provisional reference points are set.

Biomass reference values (horizontal axis)
ICES (2002) discussed a potential reference value for spawning-stock biomass: "a precautionary reference point for eel must be stricter than universal provisional reference targets. Exploitation, which provides 30% of the virgin (F=0) spawning-stock biomass is generally considered to be such a reasonable provisional reference target. However, for eel a preliminary value could be 50%." That is: ICES advised to set B_{lim} above the universal value of 30%, at a value of 50% of B_0. ICES (2007) added: "an intermediate rebuilding target could be the pre-1970s average SSB level which has generated normal recruitments in the past." The EU decided to set B_{lim} at 40% of B_0, in-between the universal level (30%) and the level advised by ICES (50%).

Mortality reference values (vertical axis)
ICES has not advised on specific values for mortality-based reference points, but the wordings "the lowest possible level" and "as close to zero as possible" imply that F_{lim} and therefore A_{lim} should be set close to zero. Over the years, the implied time frame for this advice has changed from "until a plan is agreed upon and implemented", to "until stock recovery is achieved" and "until there is clear evidence that the stock is increasing". The first and third phrases are more interim precautionary mortality advice than clear reference point related to any biomass.

The Eel Regulation (Council Regulation 1100/2007) sets a limit for the escapement of (maturing) silver eels, at 40% of the natural escapement (that is: in the absence of any anthropogenic impacts and at historic recruitment). Thus, for an eel stock with a biomass of escaping silver eel ≥ 40% of the biomass in the pristine situation, this corresponds to a lifetime mortality limit of ΣA lim = 0.92 (unless strong density dependence applies). In other words a minimal escapement of 40% of the currently best achievable escapement B_{best} is taken as a limit on mortality (%SPR = 40). However, the Eel Regulation does not define which (reduction in) mortality should be adhered to if $B_{current}$ is < than B_{lim}.

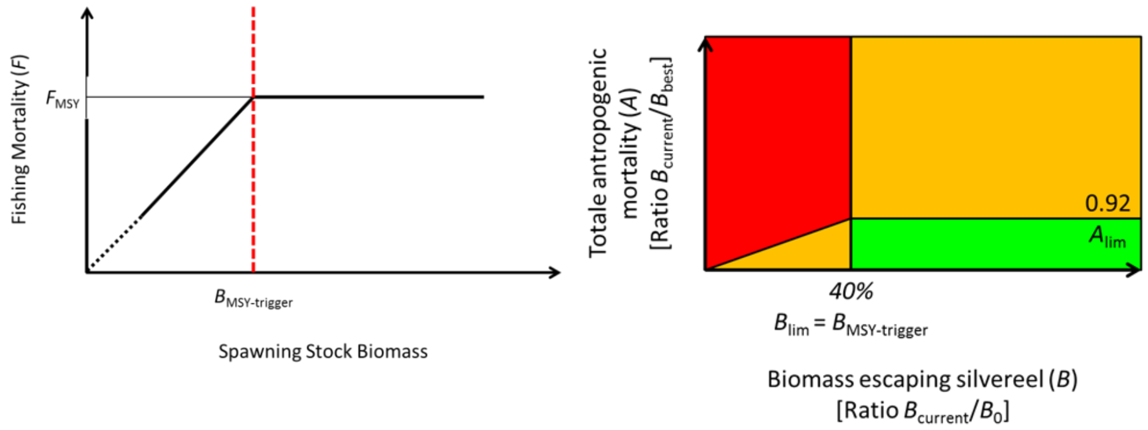

Figure 8.4 Suggested reduction in fishing mortality (F) if $B_{current} \leq B_{MSY\text{-}trigger}$ (left; ICES 2011a) according to ICES protocol. Suggested references points (A_{lim}, B_{lim}, $B_{MSY\text{-}trigger}$) and reduction in anthropogenic mortality if $B_{current} \leq B_{MSY\text{-}trigger}$ within the modified precautionary diagram (left; ICES 2011b) with respect to ***management*** *targets.*

As an initial option, ICES (2014 and references therein) recommended for eel to set $B_{MSY\text{-}trigger}$ at B_{lim}, and to reduce the mortality target below $B_{MSY\text{-}trigger}$ corresponding to ICES protocol (*Figure 8.4*). For long-lived stocks with population size estimates, ICES bases its advice on attaining an anthropogenic mortality rate at or below the mortality that corresponds to long-term biomass targets. However, $B_{MSY\text{-}trigger}$ is a biomass level triggering a more cautious response. Below $B_{MSY\text{-}trigger}$, the anthropogenic mortality advised is reduced, to reinforce the tendency for stocks to rebuild. Below $B_{MSY\text{-}trigger}$, ICES applies a proportional reduction in mortality reference values (i.e. a linear relation between the mortality rate advised and biomass; Figure 8.4).

The modified ICES precautionary diagram developed by ICES (2014 and references therein) needs to be carefully interpreted. The target biomass (40% B_0) has **not** been scientifically assessed to determine if it can be used as a true precautionary biological limit reference point. In other words, if all Member States were at 40% B_0 would the eel stock be considered to be “recovered”? Furthermore, as ICES derived the A_{lim} from the Eel regulation’s (management target) B_{lim} (40% B_0), with a reducing scale of A below B_{lim}, again there is no guarantee that if mortality is reduced below that level, the eel stock will recover.

Therefor the diagram is acceptable in principle to demonstrate the status of the eel stock with respect to the **management** targets/limits (40% B_0 and A_{lim} derived from 40% B_0) as formulated in the EC Eel Regulation, but ACOM has until now been reluctant to advise on the status of the eel stock without scientifically testing the targets/limits developed by ICES (2014 and references therein) to ensure they are precautionary and will lead to a recovery.

8.4 Evaluation

The status of the eel population in 2005-2007, 2008-2010 and 2011-2013 and hence, the evaluation of the Dutch Eel Management Plan is graphically presented in *Figure 8.5*, using the ICES Modified Precautionary Diagram with respect to the management targets from the EC Eel Regulation. The evaluation demonstrated that before and after the implementation of the EMP the status of eel in Dutch waters remained in a situation regarded as "undesirable" (high mortality, low biomass). Current biomass of escaping silver eel is below the target of 40% of the pristine situation and current anthropogenic mortality is above the recommended mortality at such low biomass of escaping silver eel (following the modified precautionary diagram developed by ICES 2014 and references therein).

Table 8.2 Stock indicators used to evaluate the impact of the EMP on the biomass of escaping silver eel (horizontal axis modified precautionary diagram) and anthropogenic mortality (vertical axis modified precautionary diagram).

	2005-2007	**2008-2010**	**2011-2013**
Stock Indicator	**Estimate**	**Estimate**	**Estimate**
B_0*	10,400 t	10,400 t	10,400 t
$B_{8current}$	897 t	1035 t	1057 t
B_{best}	3187 t	1900 t	1697 t
ΣA	1.27	0.61	0.47

* Excluding coastal waters (2600 t) (Ministry of Agriculture, Nature and Food quality (2009))

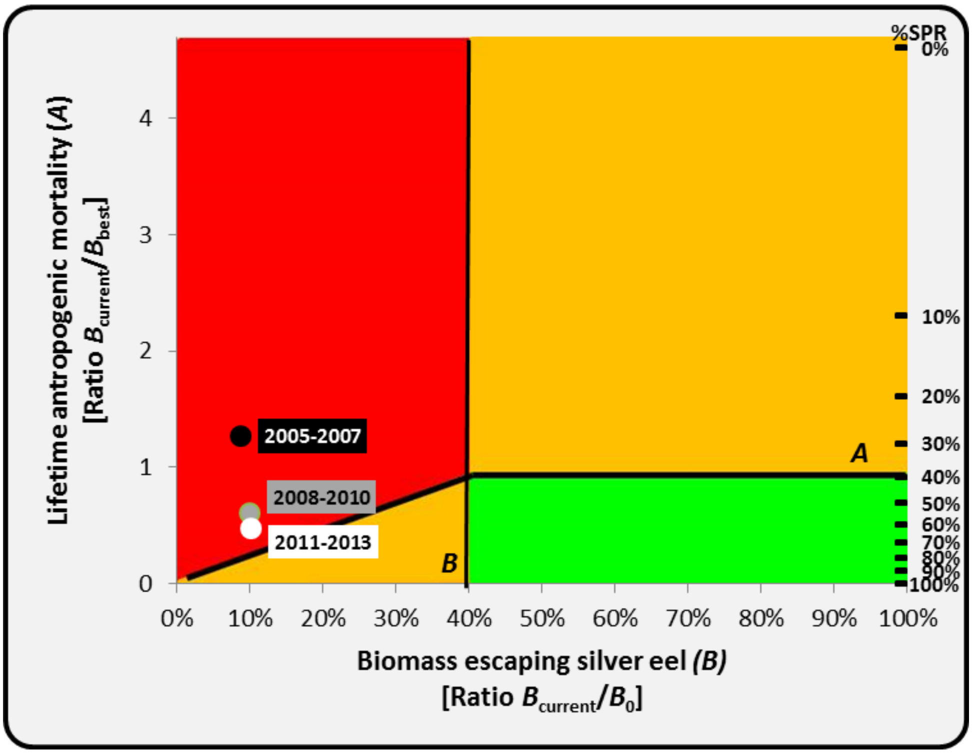

*Figure 8.5 ICES modified precautionary diagram presenting the status of the eel stock in the Netherlands in 2005-2007, 2008-2010 and 2010-2013 with respect to **management** targets. The horizontal axis represents the status of the stock in relation to pristine conditions (spawner escapement expressed as a percentage of the pristine escapement), while the vertical axis represents the impact made by anthropogenic mortality. %SPR = spawner potential ratio, a measure for the survival to silver eel relative to pristine conditions.*

Measures to reduce anthropogenic mortality are relatively quick and easy to implement and will directly result in measurable improvements (vertical axis). A reduction in anthropogenic mortality is therefore a good indicator of the drive and prowess of a member state. In the Netherlands the implementation of the EMP has resulted in a sharp reduction in anthropogenic mortality (*Figure 8.5*) between 2005-2007 and

2008-2010. The observed reduction in anthropogenic mortality was almost solely the result of a decrease in fishery mortality, both commercial and recreational. Landings of both commercial and recreational fishery have been roughly halved between 2005-2007 and 2008-2010. The remaining measures (hydropower plants, pumping stations etc.) have had limited measurable impact on the reduction in mortality during this period. Between 2005-2007 and 2008-2010 the contribution of barrier mortality nearly doubled (*Figure 8.6*) most likely due to increase in number of silver eel surviving the fishery and having to pass barriers during their migration to the sea. Between 2008-2010 and 2011-2013 a further modest decrease was observed in lifetime anthropogenic mortality (*Figure 8.5*). This modest reduction was again mainly due to a further reduction in commercial and recreational fishery mortality. The small increase in barrier mortality between 2008-2010 and 2011-2013 is more complex to interpret. In the first place it appeared that the implemented changes in turbine management of hydropower stations have had little effect on the survival of eel passing through the turbines of a HPS (see Chapter 6). The overall mortality of eels passing a barrier did, however, decrease from 16% to 15% in the model (Table 6.4). The slight reduction in mortality in the model was achieved by infrastructural changes to improve migration at some of the Top-60 migration barriers (see Chapter 6). Due to a further reduction in fishing mortality between 2008-2010 and 2011-2013 more eel survive to the start of the silver eel migration. While the average mortality of eels passing a barrier *decreased* from 16% to 15% this positive effect was most likely masked by an *increase* in the number of eels passing through migration barriers and hence a further increase in the contribution of barrier mortality to the lifetime anthropogenic mortality (*Figure 8.6*). The main source of quantified anthropogenic mortality in 2011-2013 remained commercial and recreational fishing mortality (*Figure 8.6*).

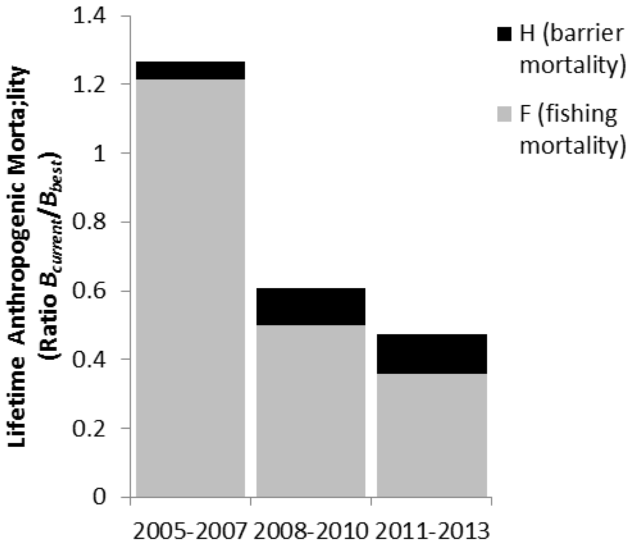

Figure 8.6 Changes in the contribution of F (fisheries mortality) and H (barrier mortality) to the life time anthropogenenic mortality of eel in the Netherlands.

Between 2005-2007, 2008-2010 and 2011-2013, a modest increase in the biomass of escaping silver eel was observed (horizontal axis; *Figure 8.5*). In 2011-2013 $B_{current}$ reached 10% of B_0 and 25% of the target biomass (40% B_0). A large increase was also not expected as current silver eel escapement has largely been determined by processes (recruitment, anthropogenic mortality) that occurred in the previous 5-15 years. Furthermore, an increase in glass eel recruitment after the implementation of the EMP 2009, will at the earliest result in an increase of silver eel after 5-15 years (2014-2025).

The maximum that can be achieved by the Netherlands on the short term is a reduction of anthropogenic mortality to as close to zero as possible. If the Netherlands would reduce anthropogenic mortality to zero, there will be no guaranty that the European eel stock will truly recover. In order to achieve a genuine recovery of the eel stock, similar levels of protection of the eel will have to be accomplished throughout its range (inside and outside Europe). Even then there is no guarantee for the recovery of the European eel stock because the actual cause of the decline of the eel is still unknown. The European eel directive is only developed to cover the risk that the decline of the European eel population is due to a decline in silver eel escapement due to anthropogenic mortality.

In other words, the Netherlands can be hold accountable for a (lack of) changes in anthropogenic mortality (vertical axis) in the modified ICES precautionary diagram. However, whether in the long term an increase in escaping silver eel as a result of an increase in recruitment will be observed in the Netherlands is depending on the protective actions undertaken in other (non-)European countries. The Netherlands, like other countries share the responsibility for improvement of the biomass of escaping eel, the horizontal axis in the modified ICES precautionary diagram.

8.5 The uncertainties of the current evaluation

The estimates of the stock indicators B_{best}, $B_{current}$, B_0 and $\sum A$ used to evaluate the status of the stock in Figure 8.4 need to be interpreted with care due to the significant level of uncertainty surrounding these estimates. The range of uncertainty around the stock indicators is visualized in *Figure 8.7*.

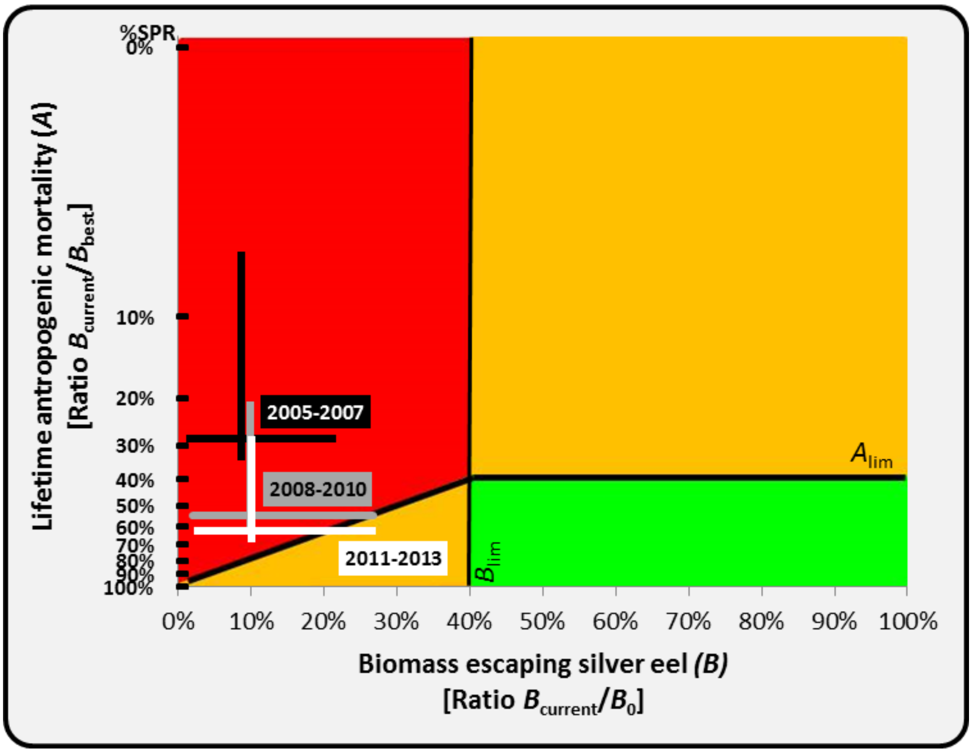

Figure 8.7 ICES modified precautionary diagram illustrating the uncertainties around the biomass estimates of escaping silver eel (range B_0; Eijsackers 2009) and estimates of anthropogenic morality (scenarios 1-3 Table 7.5) in the Netherlands in 2005-2007, 2008-2010 and 2011-2013 with respect to ***management*** *targets. The horizontal axis represents the status of the stock in relation to pristine conditions, while the vertical axis represents the impact made by anthropogenic mortality. %SPR = spawner potential ratio, a measure for the survival to silver eel relative to pristine conditions.*

Horizontal axis "biomass": Initially the amount of silver eel biomass (B_0) that would have existed in the Netherlands if no anthropogenic influences had impacted the stock, was set at 10.000-15.000 ton with a target biomass (40% B_0) of 4000-6000 t (Klein Breteler 2008). Eijsackers et al. (2009) reviewed the calculations of Klein Breter (2008) and concluded that a target biomass (40% B_0) of silver eels lies realistically more between 2600-8100 t (or B_0 = 6500-20250 t). During the review of the national eel management plans (ICES 2010), ICES did not accept all arguments of Eijsackers et al. (2009) and set B_0 at 13000 t with a corresponding escapement target of 5200 t. Like Eijsackers et al. (2009) and ICES (2010) in 2013 a second review (Rabbinge et al., 2013) of B_0 values for the Netherlands concluded that the original method to calculate B_0 was fundamentally of good quality with respect to adhering to the guidelines set by the Eel Regulation. However, de Graaf et al. (2013) and Rabbinge et al. (2013) demonstrated that conditions for a level playing field among MS when calculating B_0 were not met. Fundamental differences existed among the Netherlands, Belgium, Germany and the UK with respect to converting fisheries landings to silver eel production, selection of the reference period and correcting for glass eel stocking when calculating B_0. ICES (2010) already noted that Germany, Belgium and the UK probably underestimated B_0. If B0 in the Netherlands would have been calculated using the assumptions and methodologies of neighbouring countries like Belgium, Germany and the UK, B0 would have been significantly lower. An independent review and standardization of methodologies is more likely to result in a higher B0 for surrounding countries than a reduction of the current range (2600 – 8100 t) for the target biomass (40% B0) used in the Netherlands. The need, however, for a “level playing field” was also acknowledged by the European Commission which intends to request an external scientific review of the methodologies used by Member States, and, where relevant, an update or a new estimation of stock indicators regarding eel (European Commission 2014). A robust, independent international review of the different methods to calculate the stock indicators is required to create a level playing field, to enhance trust among MS, to ensure the recovery of the European eel stock and to guarantee a sustainable exploitation of eel.

The current evaluation of the Dutch EMP is limited to the *inland waters* only. The B_0 values (13000 t range 6500-20250 t) have been corrected for inland waters in the modified ICES precautionary diagram. On the horizontal axis the range around the estimate for the biomass of escaping silver eel is set by the values of B_0 = 10400 t (range 5200-16200 t) and 40% B_0 = 4160 t (range 2080-6480 t). In 2011-2013 $B_{current}$ has reached 10% of B_0 and 25% of the target biomass (40% B_0), however, the uncertainty was high ranging from 2-27% and from 5-68% respectively.

<u>Vertical axis “mortality”:</u> On the vertical axis the range around the estimates for lifetime anthropogenic mortality set by the values of B_{best} and $B_{current}$ (*Table 7.5*). $B_{current}$ is strongly influenced by assumptions on the efficiency of the electrofishing gear, distribution of eel over the total surface of a water body in the static spatial population model and assumptions of F when estimating eel populations using the demographic population model for some of the larger lakes (see Chapter 3).
Finally the estimated lifetime anthropogenic mortality in this report is most likely an *underestimate* of the true life time anthropogenic mortality as not all sources of mortality have been quantified and accounted for:

- poaching
- yellow eel mortality in hydropower plants and pumping stations
- the “unknown” mortality observed in the telemetry studies in the River Meuse (Table 6.3)
- impact of human-induced viruses, parasites and pollution

When interpreting the impact of the eel management plan on the status of the eel stock in the Netherlands using the modified ICES precautionary diagram, it is of utmost importance to keep the following three aspects in mind:

- the limits/targets are management limits/targets and do not guarantee a recovery of the stock,
- the uncertainties surrounding the estimated indicators B_{best}, $B_{current}$, B_0 and $\sum A$, and
- the unquantified sources of anthropogenic mortality.

9. Conclusions and recommendations

In this report, we have described the data and methods which were used to estimate the stock indicators B_{best}, $B_{current}$, B_0 and ∑A for the periods 2005-2007, 2008-2010 and 2011-2013, which were requested by the European Commission to evaluate the progress of the Dutch Eel Management Plan and the status of the European eel stock. Here, we highlight the main advantages and disadvantages and uncertainties of the used methodologies and provide recommendations for further improvements of the models for the 2018 evaluation.

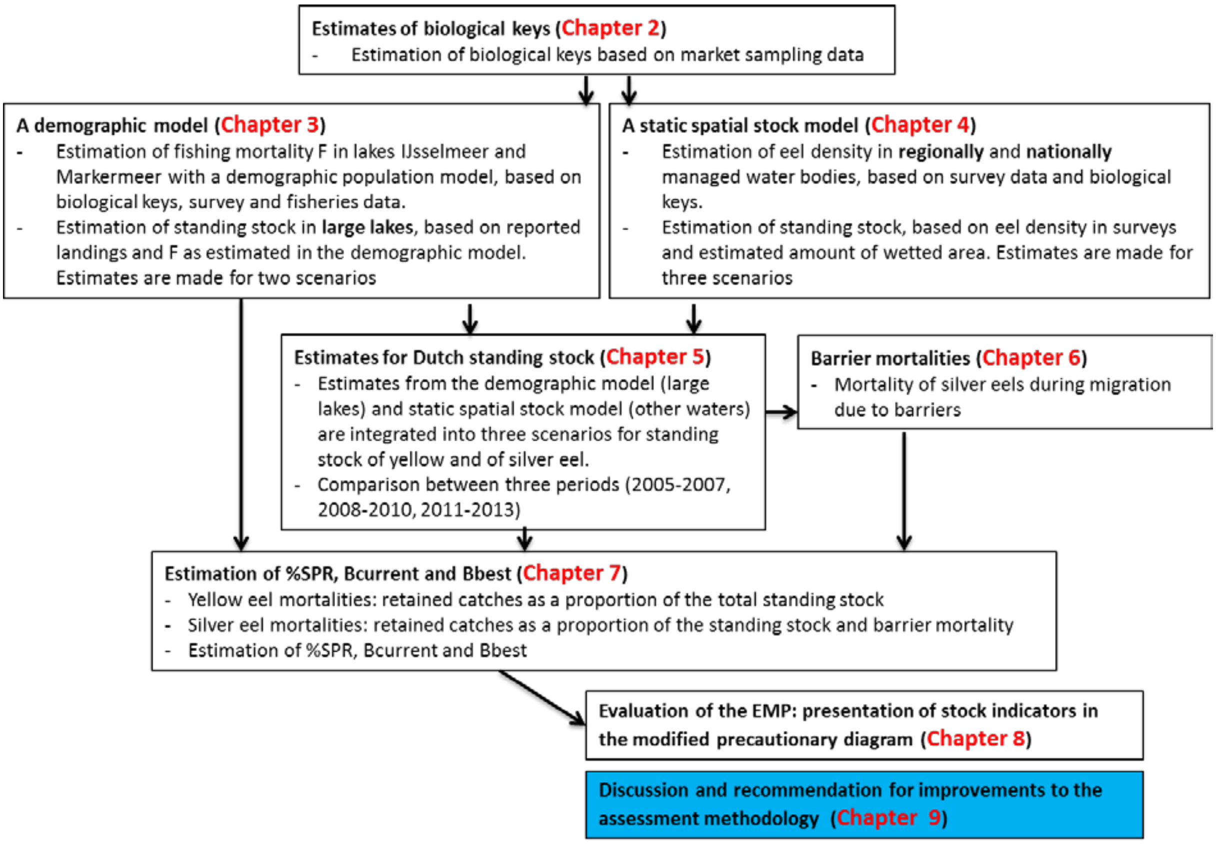

Figure 9.1 Flow chart of the assessment procedure.

9.1 Demographic model

The eel demographic model used in this study has played an important role in the final assessment by estimating fishing mortality in the large lakes and estimating the contribution of anthropogenic mortality during the yellow eel stage to Lifetime Anthropogenic Mortality (LAM).

The impact of yellow eel mortality on silver eel production was estimated using the demographic model as presented in Chapter 3. The demographic model incorporates the key biological processes of eels during the yellow eel stage; sex-specific growth, death and sex-specific maturation. However, this model is necessarily an abstraction of reality. A number of modelling assumptions were made, and varying these modelling assumptions may lead to different estimates of silver eel production. Uncertainty and possible biases in the model estimates may also arise from the parameter estimates.
The following parameters are crucial:
Sex-ratio. The higher the proportion of females, the higher the expected silver eel biomass per glass eel: females grow larger and older and (after several years of age) faster than males. Thus, higher estimated proportions of females increases the estimated fishing mortality.
Growth rates. The higher the assumed growth rate, the higher the expected silver eel biomass per glass eel: increased growth leads to increased maturation rates and hence faster exit of silver eel from the population, which therefore no longer suffer from fishing mortality. Thus, higher estimated growth

rate decreases the estimated fishing mortality (see also Dekker 2000). In general, the demographic model could be improved by allowing for variation between individuals in growth rates. Allowing for such variation could lead to different model predictions than just assuming an average growth rate. For example, given high mortalities, eels that grow at average speed will have a low expected spawner production to recruit ratio than fast growing individuals, since they are longer prone to fishing mortality. With the current parameterization of growth at age male eels grow slightly faster than with the parameterization used by Bierman et al. (2012). This increased growth rate results in a decrease of the estimated fishing mortality.

Maturation-at-length. If individuals are assumed to mature at smaller lengths, estimates of fishing mortalities will decrease as silver eel are assumed to leave the population. The proportions of silver eel out of all eels in the retained catches have been used for estimating transition maturation-at-length rates. Depending on the specifics of the fisheries sampled this may lead to an over- or under-representation of silver eels in the Dutch eel population. However, samples are taken over a five months period, including the period close to the start of migration in order to mitigate over or under estimation as much as possible.

Different estimates of growth rate and maturation-at-length were used in other studies. Witteveen & Bos (2010c), van der Meer (2010) and Dekker (2000) used a constant 3.5 cm per year as a growth curve for both sexes. In contrast, in this report a sex-specific growth curve based on otolith readings is used in which individuals grow faster in the first few years of their lives as yellow eels. With respect to maturation-at-length, eels were assumed to mature at lengths of 45 (males) and 65 cm (females) in van der Meer (2010). The estimates in Dekker (2000) cannot easily be reproduced because they are presented in graphical form. It is hard to decide at this point which of the models gives the best predictions, given the uncertainty and possible biases in the data used to estimate vital parameters in the models such as sex-specific growth rates, weight-at-length, and maturation-at-length. However, we prefer the model presented in this report on the grounds that is parameterised using extensive recent data of the key biological parameters, collected on eels in the Netherlands.

Given that it is difficult to obtain unbiased estimates of these crucial parameters fishing mortalities based on eel population models (Chapter 3) remain uncertain and require careful interpretation.

The usefulness of the demographic model for estimating fishing mortalities using only relative length-frequencies is limited. To interpret present-day data or historical stock trends, a good index of recruitment, trends in sex-ratios, sex-specific growth rates, natural mortalities, and migration rates between linked water bodies are required. Because eel recruitment and eel densities has fallen sharply, it is probably unrealistic to assume that vital parameters have remained constant. In many water bodies in the Netherlands, length-frequency distributions have shifted towards on average large individuals; mean lengths in stock surveys have been increasing in Lakes IJsselmeer, Markermeer and upper reaches of the main rivers. However, a multitude of factors may have caused this, such as decreased natural or anthropogenic yellow eel mortality, a decreased recruitment rate leading to a change in sex ratio.

The best studied and most data-rich situation is provided by lakes IJsselmeer and Markermeer for which good recruitment indices and a long-term length disaggregated stock survey are available. The main stock trends in lake IJsselmeer - a decreasing recruitment of young eels and an absolute increase in the abundance of larger eels - could be explained reasonably well by the model, mainly by decreasing the estimated fishing mortality over time. For Lake Markermeer, model fit was much lower. However, a central trend in the stock data - increasing mean length in the last few years - is based on a very low number of individuals caught. This makes the use of the survey data for this lake – and the resulting estimated fishing mortality - highly questionable. An additional survey in Lake Markermeer targeting the shores might improve the lack of individuals, but this survey has not been in place for many years, which is needed for the demographic model. Combining the two surveys may be a possibility in obtaining a data set with enough individuals, but is a daunting task given the differences in methods, habitat, season and the number of years the programs are running.

An alternative interpretation of the observed stock trends is that they were caused by immigration of silver eels from nearby water bodies such as the Veluwerandmeren or even more upstream via the river IJssel. Therefore, estimates of fishing mortalities, even for these “data rich” lakes, using the population model remain highly uncertain, and may be misleading.

9.2 Static spatial model

Anthropogenic mortalities during the yellow eel stage have been estimated using the proportion of the estimated retained catches from the commercial and recreational fisheries, out of the total estimated standing stock of yellow eel with lengths above 30 cm (both types of fisheries are assumed fully selective from 30 cm onwards and fully unselective for eels with lengths below 30 cm). Estimates of the standing stock of yellow eel were based on fisheries independent survey data (except the four large lakes), where catches per unit of effort from electric dipping nets (and for some water bodies also other gears) were used to estimate total standing stocks by scaling to total wetted areas of water bodies.

The main advantages for estimating standing stocks using the survey approach are:

- The estimates are based on large amounts of survey data which are collected using standardised protocols.
- The estimates are based on a transparent methodology, which relies mostly on two simple parameters (catch efficiency and eel distribution within and outwith of 1.5 meters of the shore/bank). Experiments can be devised which can test the assumptions and to obtain better estimates.
- The estimates, because they are specific to water bodies, can be compared with independent estimates of standing stock such through capture-mark-recapture experiments.
- The estimates are spatially explicit, and can thus be used to obtain estimates of barrier mortality during migration.
- This modelling approach can be extended to other species than eel.

The main weakness in the methodology is the uncertainty surrounding estimates of catch efficiencies and scaling of density over available wetted area of water bodies which are crucial parameters in the eel stock assessment. This lack of knowledge results in uncertainty around the estimates of standings stocks as reflected by the range in predictions using the three scenarios with differing catch efficiencies and eel distributions. To improve the quality of the method, we recommend to collect more information on these crucial parameters. A necessary improvement made to the survey model is the more detailed representation of the ditches, which are not included in the WFD. Also more effort was made to sample ditches.

Regionally managed waters

In the biomass assessment for the regional managed water bodies choices and assumptions were made based on data availability, time constraints and practicalities. The main problem with WFD fish survey data is the lack of accessibility due to the lack of a central database. For example, not all water bodies were sampled within the WFD sampling program at this point, and not all regional water boards provided sample data, all of which were not available for this analysis. In addition, in the obtained data set data points were present that could not be linked to a water body (nearly 30%), and these were excluded from analysis. Such a mismatch might be due to measurement error in GPS equipment or errors in data entry, such as missing entries or typing errors in water body names. The data eventually used in this assessment were not screened in detail for typing errors and errors in for example identification of water types due to time constraints.

As part of the WFD fish monitoring protocol, data on habitat is collected. However, in the current assessment WFD eel densities in regionally managed waters were not corrected for habitat.

Nationally managed waters

There are some shortcomings and uncertainties in the methodology used for the nationally managed waters. The main rivers in the nationally managed waters have non-connected water bodies that are in the river flood plain, within the winter dykes of the river, and are only connected to the river for a short period of time per year. No eel surveys are conducted in these waters and these water bodies are excluded in the current assessment. However, the surface area of these non-connected water bodies (64 ha) is probably negligible.

Eels are not equally distributed among the different habitat in the littoral zone. For example, in the main rivers eel densities are expected to be higher in complex habitats like groynes. At present eel densities in nationally managed waters are not corrected for habitat (sand, vegetation, rocks).
Different river regions are surveyed in different months. As a result different mean water temperatures, different eel behaviour and different silver eel migration activity, may have influenced the observed densities.

In the current assessment the standing stock of eel in the lakes IJsselmeer, Markermeer, Veluwerandmeren and Grevelingen was determined using the dynamic population model due to the lack of adequate survey data. Capture-mark-recapture studies could provide independent estimates of standing stock in these lakes. A better understanding of the distribution of eel over the surface of these large lakes may allow for the standard up scaling of eel densities from the littoral zone over the whole lake as described in the static spatial model. An alternative could be the development of an electro-beam trawl designed to effectively capture eel >30 cm length in large lakes and wide rivers.

9.3 Silver eel migration model

Compared to the model approach used for the previous evaluation study of the Dutch Evaluation Plan for 2009-2011 (Bierman et al. 2012), the approach now used relies less on overall average estimates and is more based on site-specific data. For polder waters, due to the large number of polders and lack of site-specific data for most of these sites, a similar approach of using average mortalities has been used. However, for the boezem and national waters, in this evaluation study a more bottom up approach based on site-specific estimates for mortality rates and silver eel production based on an inventory study from 2013 (Winter et al. 2013a, 2013b). This approach will yield more accurate estimates that the more general approach based on averages as used in the 2012 evaluation, but the quality of the underlying data now used is however highly variable and often still incomplete (Winter et al. 2013a). During 2012-2014 at a few sites mitigation measures were taken, e.g. replacing pumps with high mortality rates with pumps that had lower mortality rates. The telemetry data indicate that the mortality rate at the hydropower stations in the River Meuse were not lowered due to the implementation of an altered turbine management scheme in November 2011, though no studies were performed to directly measure the effect.

This is to our knowledge the first formal model to estimate mortalities during passage of barriers which takes account of variation in starting positions and migration routes of silver eels. Additionally, we have used net mortality rates for individual barriers which account for possible alternative routes which silver eels may use (paragraph 6.2).

9.4 Estimating lifetime anthropogenic mortalities (LAM)

The mortalities during the yellow eel stage caused by commercial and recreational fishers contribute the most to the estimated LAM in all three periods. This can be explained by the fact that eels take many years to mature. Also, because escapement is expressed in terms of biomass, females, which take on average longest to mature, contribute most to this. Mortality during the yellow eel stage prevents eels from developing into silver eels. Silver eel mortalities caused by barriers and retained catches can only act on the resulting proportion out of the best possible production of silver eel (if all anthropogenic mortalities during the yellow eel stage were mitigated). This means that the present-day estimated contribution of mortality caused by retained catches of silver eel and barrier mortality contribute relative little to the estimated LAM. The estimated decrease in mortality over the periods 2005-2007 to 2008-2010 and 2008-2010 to 2011-2013 foremost to the realised decrease in yellow eel mortality.

Yellow eel and silver eel mortalities have been estimated using the estimated retained catches and barrier mortalities in relation to the estimated standing stock of eel in a particular period. The overall estimated LAM is not the same as the LAM that new recruits (glass eels) arriving in for example 2015 are expected to experience throughout their life span until escapement to the sea as a silver eel. In particular, the effect of the areas closed for fisheries (main rivers and some large canals) has not yet fully materialised; in the near future the eel stock may increase in the closed area relative to the eel stock in other parts of the Netherlands due to decreased mortality. If landings from other parts of the Netherlands stay the same relative to the stock size, then the mean fishing mortality may be expected to decrease in the near future. However, as discussed above, no empirical evidence has been found as yet of reduced mortalities during silver eel migration on the Meuse river due to the closing of the commercial fisheries.

We note that the estimated lifetime anthropogenic mortalities in this report are most likely *underestimates* of the true life time anthropogenic mortality as not all sources of mortality have been quantified and accounted for, e.g.:

- poaching
- yellow eel mortality in hydropower plants and pumping stations
- the “unknown” mortality observed in the telemetry studies in the River Meuse (Table 6.3)
- impact of human-induced viruses, parasites and pollution

9.5 Evaluation of the EMP using stock indicators

The estimated key stock indicators B_{best}, $B_{current}$, B_0 and ∑A have been evaluated in relation to management targets/limits (40% B_0 and A_{lim} derived from 40% B_0) as formulated in the EC Eel Regulation, using the modified precautionary diagram (Chapter 8). The modified ICES precautionary diagram developed by ICES (2014 and references therein) needs to be carefully interpreted. The target biomass (40% B_0) is a **management** target and has **not** been scientifically assessed to determine if it can be used as a true precautionary biological limit reference point. In other words, if all Member States were at 40% B_0 would the eel stock be considered to be “recovered”? Furthermore, as ICES (2014 and references therein) derived the A_{lim} from the Eel regulation’s (management target) B_{lim} (40% B_0), with a reducing scale of A below B_{lim}, again there is no guarantee that if mortality is reduced below that level, the eel stock will recover.

Therefor the diagram is acceptable in principle to demonstrate the status of the eel stock with respect to the **management** targets/limits (40% B_0 and A_{lim} derived from 40% B_0) as formulated in the EC Eel Regulation. However, the Advisory Committee (ACOM) of ICES has until now been reluctant to advise on the status of the eel stock without scientifically testing the targets/limits developed by ICES (2014 and references therein) to ensure they are precautionary and will lead to a recovery.

When interpreting the impact of the eel management plan on the status of the eel stock in the Netherlands using the modified ICES precautionary diagram, it is of utmost importance to keep the following three aspects in mind:

- the limits/targets are management limits/targets and do not guarantee a recovery of the stock,
- the uncertainties surrounding the estimated indicators B_{best}, $B_{current}$, B_0 and ∑A, and
- the unquantified sources of anthropogenic mortality.

9.6 Recommendations

During the development of the current models used to calculate the stock indicators, the main weaknesses of the methodology surfaced quickly. Here we list the main improvements to the calculation of the stock indicators based on the recommendations from Bierman et al. (2012) and we provide an overview of recommendations for further adjustments to improve the quality of the assessment before the next evaluation in 2018.

Demographic Model

Key biological parameters: improve to quality of the following key biological parameters

Sex-ratio: ***2012 -*** Sex ratios could be improved by using eels smaller than 30 cm. These eels could be obtained during the WFD fish sampling. ***2015 –*** Eels smaller than 30 cm are currently collected (e.g. IJsselmeer electro trawl survey) and used to determine sex ratios.

Growth rate: ***2012 -*** Growth rates could be improved by including eels smaller than 30 cm. These eels could be obtained during WFD fish sampling. ***2015 –*** Age and growth increments of eel <30 are being determined as part of the WOT eel research programme.

Maturation-at-length: The silvering ogive for a given area could be improved by using data collected year round.

Anthropogenic mortalities: ***2012 -*** quantify sources of anthropogenic mortalities that were excluded from the 2012 assessments such as 1) catch-&-release mortality of recreational fisheries, 2) yellow eel mortality pumping stations and hydropower plants, 3) poaching. ***2015 –*** A rough estimate of eel catch-&-release mortality by recreational fishers has been accounted for during the current evaluation. In 2015 experiments will be conducted in collaboration with German scientists to determine C&R mortality for eel and improve the current estimate. Quantifying yellow eel mortality by pumping stations and hydropower plants and estimating the impact of poaching remains to be done.

Survey data: Combining two surveys to increase the data pool for especially Lake Markermeer may be a possibility in obtaining a data set with enough individuals, but is a daunting task given the differences in methods, habitat, season and the number of years the programs are running.

Spatial Model

WFD survey data: ***2012 -*** Improve the accessibility of WFD fish survey data of regionally managed waters by establishing a central data base for the Netherlands, and ensure that the data is properly checked to ensure the quality of data. ***2015 –*** Accessibility of WFD fish survey data remains difficult and a central data base is highly recommended before the 2018 evaluation of the Dutch eel management plan.

Catch efficiency: ***2012 -*** Conduct experiments to determine efficiencies of electrofishing for eel in different WFD water types in both nationally and regionally managed waters. ***2015 –*** Experiments to determine efficiencies of electrofishing for eel remain to be done.

Spatial distribution*: 2012 -* Conduct experiments to determine the spatial distribution of eel in wide rivers and lakes in both nationally and regionally managed waters. ***2015 –*** In 2013 a pilot study was conducted in wide rivers to study the spatial distribution of eel. The results were ambiguous and in the coming years further (internationally co-ordinated) experiments are planned to determine the spatial distributions of eel in wide rivers and lakes for the 2018 evaluation.

Ditches: ***2012 -*** Conduct electrofishing surveys for eel in ditches to supplement the existing WFD eel survey data in regionally managed waters. ***2015 –*** Since 2013 annual electrofishing surveys for eel in ditches have been part of the WOT eel research programme.
Habitat: ***2012 -*** Correct eel densities for habitat in nationally and regionally managed waters. ***2015 –*** Correcting eel densities for habitat remains to be done.
Electro-beam trawl: ***2012 -*** Develop an electro-beam trawl to provide reliable estimates of eel (>30 cm) densities in large lakes and wide rivers. ***2015 –*** In co-operation with an environmental consultancy company an improved electro-beam trawl was developed, however, this new electro-beam trawl remains to be tested and calibrated (efficiency) and is not being used in standard surveys to date.

Silver Eel Migration Model
Migration routes: ***2012 -*** finalise the GIS model (Appendix A in Bierman et al. 2012) to improve the estimate of silver eel mortality during migration. ***2015*** Based on a new barrier assessment for migrating silver eel in 2013 silver eel mortality estimates were improved by using a weighted importance of individual barriers based on catchment size for the boezem and national waters. The barrier-mortality model as presented here to estimate mortality of silver eels during migration can be further developed to enable a full 'bottom up and site-specific data driven' approach for all types of waters and barriers.
Silver eels migrating downstream from Belgium and Germany: The mortality caused by hydropower stations on silver eels migrating downstream on the river Meuse from Belgium and the river Rhine from Germany ('foreign' silver eels) have not been taken into account in the estimation of LAM in this report. It is still unclear as it was during the 2012 evaluation, whether these mortalities should have been included in the LAM of silver eels in the Netherlands or in the country where the silver eels were produced (Germany, Belgium). It is recommended that international agreement is achieved how these mortalities should be accounted for when silver eels pass several MS during migration.

International "level playing field" stock indicators
As many other European countries (France, UK, Ireland) are using similar spatial models to estimate yellow eel standing stock and silver eel production, close international co-operation and collaboration will enhance the quality and uniformity of these models in the future. An independent international review of the methods used to estimate the stock indicators is required to create a level playing field and to enhance trust among member states. Furthermore standardization of assessment methods is of utmost importance to ensure the recovery of the European eel stock and its sustainable exploitation. The need for a "level playing field" was acknowledged by the European Commission which intends to request an external scientific review of the methodologies used by Member States to estimate the stock indicators.

10. References

- Aprahamian M.W., 1986. Eel (Anguilla anguilla L.) production in the River Severn. England. Pol. Arch. Hydrobiol., 33, 373–389.
- Baldwin, L. & Aprahamian, M. (2012) An evaluation of electric fishing for assessment of resident eel in rivers. *Fisheries Research* 123-124, 4-8.
- Bark, A., Williams, B. & Knights, B. (2007) Current status and temporal trends in stocks of European eel in England and Wales. ICES Jour-l of Marine Science 64, 1368-1378.
- Beaumont, W.R.C, Taylor, A.A.A., Lee, M.J. & Welton, J.S. (2002) Guidelines for Electric Fishing Best Practice. R&D Technical Report W2-054/TR. Environment Agency, Bristol.
- Bierman S.M., N. Tien N., van de Wolfshaar K.E., Winter H.V. & de Graaf M., 2012. Evaluation of the Dutch Eel Management Plan 2009–2011. IMARES Report C067/12.
- Breukelaar AW, Bij de Vaate A, Fockens KTW (1998). Inland migration study of sea trout (Salmo trutta) into the Rivers Rhine and Meuse (Netherlands), based on inductive coupling radio telemetry. Hydrobiologia 1998;371/372:29-33.
- Bruijs MCM, Polman HJG, van Aerssen GHFM, Hadderingh RH, Winter HV, Deerenberg C, Jansen HM, Schwevers U, Adam B, Dumont U, Kessels N. (2003) Management of silver eel: Human impact on downstream migrating eel in the river Meuse. EU-Report Contract Q5RS-2000-31141.
- Carrs, D.N., Elston, D.A., Nelson, K.C. & Kruuk, H. (1999) Spatial and temporal trends in unexploited yellow eel stocks in two shallow lakes and associated streams. *Journal of Fish Biology*55, 636-654.
- Chisnall, B.L. & West, D.W. (1996) Design and trial of a large fine-meshed fyke net for eel capture, and factors affecting size distribution of catches. *New Zealand Journal of Marine and Freshwater Research* 30(3), 355-364
- Ciccotti, E., Leone, C., Bevacqua, D., De Leo, G., Tancioni, L. and Capoccioni, F., 2012. Integrating habitat restoration and fisheries management: A small-scale case-study to support EEL conservation at the global scale. Knowledge and Management of Aquatic Ecosystems 4007.
- Davey, A.J.H. & Jellyman, D.J. (2005) Sex determination in freshwater eels and management options for manipulation of sex. *Reviews in Fish Biology and Fisheries* 15, 37-52.
- de Graaf M, van der Sluis MT, van der Waal AG. 2013. Quick Scan Streefbeeld Aal. IMARES C144/13, pp. 40.
- De Graaf, M, Deerenberg, C. (2015) Report on the eel stock and fishery in the Netherlands 2013. IMARES report C003/15.
- De Leo, G. A. & Gatto, M. (1996) Trends in Vital Rates of the European Eel: Evidence for Density Dependence? *Ecological Applications* 6, 1281-1294.
- Dekker, W. 1991. Assessment of the historical downfall of the IJsselmeer fisheries using anonymous inquiries for effort data. — In: I.G. Cowx (ed.): Catch Effort Sampling Strategies, their Application in Freshwater Management, pp. 233-240. Fishing News Books, Oxford. 420 pp.
- Dekker, W. (2000) Impact of yellow eel exploitation on spawner production in Lake IJsselmeer, The Netherlands. *Dana* 12, 17-32.
- Edeline, E., Dufour, S. & Elie, P. (2009) Proximate and Ultimate Control of Eel Continental Dispersal. I*n* Spawning Migration of the European Eel, pp 433-461. Ed. by G. van den Thillart S., Dufour and J. Cliff Rankin. Fish & Fisheries Series Volume 30, Springer Science. 477 pp.
- European Commission. 2014. Report from the Commission to the Council and the European Parliament on the outcome of the implementation of the Eel Management Plans, including an evaluation of the measures concerning restocking and of the evolution of market prices for eels less than 12 cm in length.
- Griffioen, A.B., van Keeken, O.A., Winter H.V., 2013. A telemetry study for migrating silver eel (Anguilla anguilla L.) mortality estimations in the River Meuse in 2010 – 2012. IMARES Report C028/13
- Han, Y.-S. & Tzeng, W.-N. (2006) Use of the Sex Ratio as a Means of Resource Assessment for the Japanese Eel *Anguilla japonica*: A Case Study in the Kaoping River, Taiwan. *Zoological Studies* 45, 255-263.

- Huertas, M. & Cerda, J (2006) Stocking Density at Early Developmental Stages Affects Growth and Sex Ratio in the European Eel (*Anguilla anguilla*). Biological Bulletin 211, 286-296.
- ICES (2007) Report of the 2007 Session of the Joint EIFAC/ICES Working Group on Eels. ICES Advisory Committee on Fishery Management. ICES CM 2007/ACFM:23.
- ICES (2009) Report of ICES Advisory Committee, 2009. ICES Advice. Books 1-11. 1,420 pp.
- ICES (2010) Review Service: Evaluation of Eel Management Plans. Annex of the Report of the ICES Advisory Committee 2010, Book 11, Technical Services.
- ICES (2011a) Report of ICES Advisory Committee, 2010. ICES Advice, 2011. Books 1-11. 1685 pp.
- ICES (2011b) Report of the Study Group on International Post-Evaluation on Eels (SGIPEE), 24-27 May 2011, London, UK; ICES CM 2011/SGEF:13. 39pp.
- ICES (2014) Report of the Joint EIFAAC/ICES/GFCM Working Group on Eel, 3–7 November 2014, Rome, Italy. ICES CM 2014/ACOM:18. 203 pp.
- Jansen, H.M., H.V. Winter, M.C.M. Bruijs & H. Polman (2007). Just go with the flow? Route selection and mortality during downstream migration of silver eels in relation to discharge. ICES Journal of marine Science 64: 1437-1443.
- Jellyman. D.J. & Chisnall. B.L. (1999) Habitat preferences of shorfinned eels (Anguilla australis) in two New Zealand lowland lakes. New Zealand Journal of Marine and Freshwater Research 33, 233-248.
- Klinge, M., 2008. Evaluatie van de gemaalvispassage in gemaal Meerweg te Haren. Rapport Witteveen+Bos in opdracht van Waterschap Hunze en Aa's.
- Kroes, M.J., H. Wanningen, P. van Puijenbroek, & N. Breve, 2015. Nederland leeft met Vismigratie. Actualisatie landelijke database vismigratie. In opdracht van Sportvisserij Nederland, IMARES, Planbureau voor de leefomgeving.
- Kruitwagen, G., Klinge, M., 2008a. Sterfte van schieraal door gemaal IJmuiden, onderzoeksjaar 2008, idem 2009. Rapport Witteveen+Bos in opdracht van Rijkswaterstaat Noord-Holland.
- Kunst, J.M., Spaargaren, B., Vriese, T., Kroes, M., Rutjes, C., van der Pouw-Kraan, E. & Jonker, R.R. (2008) Gemalen of vermalen worden; onderzoek naar visvriendelijkheid van gemalen. I&M-99065369-MK, pp. 70.
- Laffaille, P., Acou, A., Guillouët, J., Mounaix, B. & Legault, A. (2006) Patterns of silver eel (Anguilla anguilla L.) sex ratio in a catchment. Ecology of Freshwater Fish 15, 583-588.
- Ministry of Agriculture, Nature and Food quality (2009) The Netherlands Eel Management Plan.
- Naismith, I. A. & Knights, B. (1990) Studies of sampling methods and of techniques for estimating populations of eels, *Anguilla anguilla* L. *Aquaculture and Fisheries Management* 21, 357-367.
- Oeberst, R. and Fladung, E., 2012. German Eel Model (GEM II) for describing eel, Anguilla anguilla (L.), stock dynamics in the river Elbe system. . Information on Fishery Research 59, 9–17.
- Oliveira, K., McCleave, J.D. & Wippelhauser, G.S. (2001) Regio-l variation and the effect of lake: river area on sex distribution of American eels. *Joural of Fish Biology* 58, 943-952.
- PBL, 2010. Basiskaart aquatisch: de watertypenkaart. In: leefomgeving, P.v.d. (ed.).
- Rabbinge R, van der Meer J, Quak J, Verreth JAJ, van der Waal AG, Nagelkerke LAJ. 2013. Herberekening Streefbeeld Aal: Een analyse van het bestaande Nederlandse streefbeeld in relatie tot de buurlanden. Een advies op verzoek van de Minister van Economische Zaken, pp. 87.
- Roncarati, A., Melotti, P., Mordenti, O. & Gen-ri, L. (1997) Influence of stocking density of European eel (*Anguilla anguilla* L.) elvers on sex differentiation and zootechnical performances. *Journal of Applied Ichtyology* 13, 131-136.
- Schulze, T, Kahl, U, Radke, R.J. & Benndorf, J. (2004) Consumption, abundance and habitat use of Anguilla anguilla in a mesotrophic reservoir. *Journal of fish Biology 65* 1543-1562.
- Stevens, M., Coeck, J. & van Vessem, J. (2009). Wetenschappelijke onderbouwing van de palingbeheerplannen voor Vlaanderen. Rapporten van het Instituut voor Natuur- en Bosonderzoek 2009 (INBO.R.2009.40). Instituut voor Natuur- en Bosonderzoek, Brussel.

- STOWA (2003) Handboek Visstandbemonstering.
- Van de Wolfshaar, K.E., Tien, N.S.H., Winter, H.V., de Graaf, M., Bierman, S.M. (2014) A spatial assessment model for European eel (Anguilla anguilla) in a delta, The Netherlands. Knowledge and Management of Aquatic Ecosystems 2014 (412) 02. DOI: 10.1051/kmae/2013083
- Van der Hammen, T., de Graaf, M. (2013) Recreational fishery in the Netherlands: demographics and catch estimates in marine and fresh water. IJmuiden : IMARES, (Report / IMARES C147/13) - p. 33
- Van Keeken O., Bierman S.M., Wiegerinck J.A.M. and Goudswaard P.C., 2010. Proefproject marktbemonstering aal 2009 IMARES Report C028/10.
- Van Keeken O., Bierman S.M., Wiegerinck H., Goudswaard K. and Kuijs E., 2011. Proefproject marktbemonstering aal Voortgang 2010. IMARES Report C053/11.
- van Keeken OA, Winter HV, Griffioen AB, de Graaf M. 2013. Silver eel behaviour in the vicinity of pumping stations: a telemetry study in Friesland. IMARES C120/13, pp. 44.
- Van Keeken, O.A. , Beentjes, R., van de Wolfshaar, K.E., de Graaf, M., de Boois, I.J. (2014a) Pilot polderbemonstering 2013: beheersgebied Hoogheemraadschap Hollands Noorderkwartier. IJmuiden : IMARES, (Rapport / IMARES C039/14) - p. 31
- Van Keeken, O.A., van de Wolfshaar, K.E., Hoek, R., de Graaf, M. (2014b) Pilot polderbemonstering. IJmuiden : IMARES, (Rapport / IMARES C161/14) - p. 22
- van der Meer (2010) Van der Meer, J. (2010) Bijlage III. Enkele overwegingen betreffende de IMARES model analyse In: H. Eijsackers, L.A.J. Nagelkerke, J. van der Meer, M. Klinge & J. van Dijk (2009) Streefbeeld aal. Een deskundigenoordeel. Adviesrapport op verzoek van de minister van LNV, Den Haag.
- Vriese, F.T, Klein Breteler, J., Kroes M.J. & Spierts I.L.Y. (2007) Beheer van de aal in Nederland. Rapport VisAdvies VA2007-01.
- Walker, A. (2006) Scenario-based model for eel populations (SMEP). http://www.diadfish.org/maj2006_fichiers/maj_11_06_slime/
- Winter, H.V., Jansen, H.M. & Bruijs, M.C.M. (2006). Assessing the impact of hydropower and fisheries on downstream migrating silver eel, Anguilla anguilla, by telemetry in the River Meuse. Ecology of Freshwater Fish 15: 221-228.
- Winter, H.V., H.M. Jansen & A.W. Breukelaar (2007). Silver eel mortality during downstream migration in the River Meuse, a population perspective. ICES Journal of marine Science 64: 1444-1449 .
- Winter, H.V.; Bierman, S.M., 2010. De uittrekmogelijkheden voor schieraal via de Haringvlietsluizen. IMARES Rapport C155/10.
- Winter H.V., 2011. Effecten van gemaal IJmuiden op de uittrek van schieraal: integratie van de onderzoeken tijdens de periode 2007-2011. IJmuiden, IMARES Rapport C152/11.
- Winter, H.V., Griffioen, A.B., van de Wolfshaar, K.E. (2013a) Inventarisatie van de belangrijkste knelpunten voor de uittrek van schieraal in Nederland. IJmuiden. IMARES, (Rapport / IMARES C107/13) - p. 50
- Winter HV, Griffioen AB, van de Wolfshaar KE. (2013b). Knelpunten inventarisatie voor de uittrek van schieraal t.b.v. ‘Paling Over De Dijk’. IMARES-report C134/13.
- Yokouchi, K., Aoyama, J., Miller, M.J., McCarthy, T.K. & Tsukamoto, K. (2009) Depth distribution and biological characteristics of the European eel Anguilla anguilla in Lough Ennell, Ireland. *Journal of Fish Biology* 74, 857-871.

11. Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2017 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

12. Justification

Rapport number: C078/15
Project Number: 4311218510

The scientific quality of this report has been peer reviewed by a colleague scientist and the head of the department of IMARES.

Approved: J.J. Poos
Researcher

Signature:

Date: 20th of May 2015

Approved: J. Schobben
Head of Department Fish

Signature:

Date: 20th of May 2015

13. Appendices

Appendix A: Water types used in the WFD

Table A1: Water body types defined within the Water Framework Directive in the Netherlands that were taken into account in this study of regionally managed waters.

Code water type	Description
M1a/b	Buffered ditches
M2	Weakly buffered ditches
M3	Buffered regional canals
M6a/b	Large, shallow canals with/without shipping
M7a/b	Large deep canals with/without shipping
M8	Buffered fen ditches
M10	Fen canals
M14	Shallow, relatively large, buffered lakes
M20	Relatively large, deep, buffered lakes
M23	Shallow, large, calcium rich lakes
M27	Relatively large, shallow, fen lakes
M30	Weakly brackish waters
R4	Permanent, slow flowing, upper reach, sand
R5	Permanent, slow flowing, middle and lower reach, sand
R6	Slow flowing small river, sand-clay
R7	Slow flowing river, side channel, sand or clay
R12	Slow flowing middle and lower reach, bog
R13	Fast flowing upper reach, sand
R14	Fast flowing middle and lower reach, sand
R15	Fast flowing small river, pebble
R17	Fast flowing upper reach, calcium rich
R18	Fast flowing middle and lower reach, calcium rich

Appendix B: Barriers from polder to boezem

Table B1: Overview eel mortality when passing pump stations with a propeller pump (axial water flow). * Underestimation as physically undamaged eels did reveal internal damage after dissection which would result in delayed mortality.

	Pump description	Capacity (m3/min)	Height (m)	Rotation (rpm)	Name	n	dead (%)	damaged (%)		Reference
axiaalpump	Gesloten schroefpomp	60	0.8	355	Kortenhoef	118	32			Vriese et al., 2010
	Gesloten schroefpomp FFI	81	1	333	FFI	25	0			Vriese, 2009
	Gesloten schroefpomp	1500		50	J.L. Hoogland	77	5	5		Kruitwagen & Klinge, 2010a
	Gesloten schroefpomp	2500	0.6	80	A.F. Stroink	10	0	30		Kroes et al., 2006
	Open schroefpomp	24	0.98		Thabor	21	38			Vriese et al., 2010
	Open schroefpomp	60	2.7	500	Stenensluisvaart	?	100			Germonpré et al., 1994
	Open schroefpomp	76			Offerhaus	10	0			Vriese, 2010
	Open schroefpomp	200	0.6	165	Den Deel	?	8	30		Riemersma & Wintersmans, 2005
	Bulbpomp Nijhuis	3000	variable	64	IJmuiden	251	41*	41*		Kruitwagen & Klinge, 2008a
	Schroefpomp	30	1.35	900	Kralingseplas	19	100			Kruitwagen & Klinge, 2010b
	Schroefpomp	400	1,34-4,64		Krimpenerwaard	19	100			Kruitwagen & Klinge, 2010b
	Schroefpomp	184	1.05	185	De Waker	69	1.4			VisserijServiceNederland, 2010
	Schroefpomp	2400			Zaangemaal	65	0			VisserijServiceNederland, 2010
	Schroefpomp	180	1.07	180	Meldijk	30	33			Kroon & van Wijk, 2012
	propeller	60	2.7	500	Woumen (BE)	?	100			Germonpré et al., 1994
	propeller	100		480	Avrijevaart/Burgraven (BE)	39	98			INBO
	BVOP	255	5.4	360	Lijnden	*2*				
	Gesl. Schroefp. (compact)	90	2.7	364	HZ Polder	*6*				Vriese et al., 2010
	Gesl. Schroefp. (compact)	105	2.2	291	Berkel	*5*				Vriese et al., 2010
	Gesl. Schroefp. (compact)	135	0,5-1	307	Antlia	*6*				Vriese et al., 2010
	Gesloten schroefpomp	26	3.08		Makkemermar	*2*				Vriese et al., 2010
	Gesloten schroefpomp	42	2,4 - 3,1		Aalkeet buitenpolder	*1*				Kruitwagen & Klinge 2010c
	Open schroefpomp	40	1.67	580	Nijverheid	*2*				Vriese et al., 2010
	Open schroefpomp	120	0.1		Tilburg	*9*				Vriese et al., 2010
	Gesloten schroefpomp FFI				Kralingseplas	*3*				Waning et al., 2012
	Open schroefpomp	90			Offerhaus	*2*				Kroes & de Boer, 2013
	schroefpomp	120	340	340	Balgdijk	*5*				Kroon & van Wijk, 2012
					Pooled studies with n <10		32.6			
							40.5	**26.5**	**53.8**	

Table B2 : Overview eel mortality when passing pump stations with a propeller-centrifugal pump (axial-radial water flow).

	Pump description	**Capacity (m3/min)**	**Height (m)**	**Rotation (rpm)**	**Name**	**n**	**dead (%)**	**damaged (%)**		**Reference**
semi-axiaal pump	Schroefcentrifugaalpomp	170	1.52		Tonnekreek	34	0			Vriese et al., 2010
	Hidrostal		10	890-1200		2300	0	3		Patrick & McKinley 1987
	Schroefcentrifugaalpomp	350	2.8	115	Schilthuis	27	22			Vriese et al., 2010
	BEVERON	505	2,4	143	Schoute (natuurlijke doortrek)	36	0			Kruitwagen & Klinge, 2008b
	BEVERON	525	5.4	200	Lijnden	*6*				
	Hidrostal	21	3.6	577	Ypenburg	*8*				Vriese et al., 2010
	Hidrostal	42.5	3.5	552	Wogmeer	*8*				Vriese et al., 2010
	Schroefcentrifugaalpomp	300	4.4		Leemans	*4*				Kroon & van Wijk, 2013
	Schroefcentrifugaalpomp	250	2-5,5	165	Abraham Kroes (Ringvaart gemaal)	*8*				Kruitwagen & Klinge, 2010b
	VOPO met schroefomdraaiing	25	0.15	1000	De Zllk	*2*				Vriese et al., 2010
	Schroefcentrifugaalpomp	85		416	Willem-Alexander	*1*				Vriese et al., 2010
	Schroefcentrifugaalpomp	24	1.15		B.B. Polder	*2*				Vriese et al., 2010
	Schroefcentrifugaalpomp	22	1.15	735	Meerweg	*9*				Klinge, 2008
					Pooled studies with n <10		39.6			
							7.7	**3**	**9.2**	

Table B3 : Overview eel mortality when passing pump stations with a centrifugal pump (radial water flow).

	Pump description	**Capacity (m3/min)**	**Height (m)**	**Rotation (rpm)**	**Name**	**n**	**dead (%)**	**damaged (%)**		**Reference**
radial pump	Centrifugaalpomp	38	3.5	368	Duifpolder	12	0			Vriese et al., 2010
	Centrifugaalpomp	60	5	49	Elektriek-Zuid	?	1.4	1.4		Germonpré et al., 1994
	Centrifugaalpomp	400	0.9	205	Boreel	49	49			Vriese et al., 2010
	Centrifugaalpomp	1080	1.7	59	Katwijk	56	0			Kruitwagen & Klinge, 2007
	Centrifugaalpomp	325	3.5	168	Grootslag	438	0			Kroon & van Wijk, 2013
	Centrifugaalpomp	160	0.3		JC de Leeuw	*5*				Kroon & van Wijk, 2013
	Centrifugaalpomp	690	1.7	70	Gouda (natuurlijk)	*2*				Kruitwagen & Klinge, 2008c
	Centrifugaalpomp	690	1.7	70	Gouda (gedwongen)	*4*				Kruitwagen & Klinge, 2008c
	Centrifugaalpomp	28	0,55-1,05	320	Hoekpolder	*1*				Kruitwagen & Klinge, 2010c
					Pooled studies with n <10		16.7			
							11.2	**1.4**	**12.4**	

Table B4 : Overview eel mortality when passing pump stations with an Archimedes screw.

	Pump description	Capacity (m3/min)	Height (m)	Rotation (rpm)	Name	n	dead (%)	damaged (%)		Reference
Archimedes screw	Turbinevijzels				Vijzel Bielefeld	?	0			Spah, 2001
	Buisvijzel FFI	0.6	1	57	FFI (gedwongen blootstelling)	23	0			Vriese, 2009
	Vijzel	30	2.9	39	Sint-Karelsmolen	?	4	10		Germonpré et al., 1994
	Vijzel	35	3.6	37	De Seine, Vlaanderen	?	0	37		Denayer & Belpaire, 1992
	Spaans Babcock	500	2.2	17	Overwaard	43	2			Vriese et al., 2010
	De Wit vijzel	660	0.3	22	Halfweg (natuurlijke doortrek)	24	0			Kruitwagen & Klinge, 2008c
	Buisvijzel (Landustrie Sneek BV)	40	2.7	39.1	Ennemaborgh	101	8			Vis et al., 2013
	Buisvijzel (Landustrie Sneek BV)	23	2.7	23.8	Ennemaborgh	*112*	3			Vis et al., 2013
	Vijzel	335	0.35		Kolhoorn	16	0			Kroon & van Wijk, 2013
	Vijzel	350	1.14		Kadoelen	59	8			VisserijServiceNederland, 2010
	Vijzel			23-31		160	0	0.6		Kibel, 2008
	Vijzel	100		25	Isabella	48	13.5			INBO
	Vijzel	200		21	Isabella	131	14.5			INBO
	Vijzel	90	0.64		Overtoom	*7*				VisserijServiceNederland, 2010
	Vijzel	43	1.25		Bergermeer	*3*				VisserijServiceNederland, 2010
	Vijzel	660	0.3	22	Halfweg (natuurlijke doortrek)	*5*				Kruitwagen & Klinge, 2008c
	Buisvijzel FFI	32			Hoekpolder	*2*				Wanink et al., 2012
	Vijzel				Schalsum	*2*				Koopmans, 2013
	Vijzel	23	0.73		Sudhoeke	*9*				Vriese et al., 2010
					Pooled studies with n <10	28	3.6			
							4.0	**15.9**	**12**	

Appendix C. Barrier list Winter et al. (2013a, 2013b)

Table C1. Overview of the most important barriers, their characteristics and their estimated mortalities (Winter et al. 2013a, 2013b).

Knooppunt	Type kunstwerken	min verlies (ton)	max verlies (ton)	min verlies (%)	max verlies (%)	RANK	Vervolg route naar zee	boezem-r	via-rijks-o	MIN % 11-	MAX % 11	MIN TON	MAX TON
Alphen/Lith (Maas)	Wkc+Stuw+Vist+Sche	11.96	11.96	15.00	15.00	1		W		15.00	15.00	1195.95	1195.95
Linne (Maas)	Wkc+Stuw+Vist+Sche	7.37	7.37	17.00	17.00	2	WKC Alphen → zee	W		17.00	17.00	736.78	736.78
Stroink	Gema	6.24	6.24	50.00	50.00	3	Afsluitdijk → zee	B	r	11.00	11.00	137.28	137.28
Sluizen-complex IJmuiden	Gema+Spui+Sche	2.38	4.60	1.50	2.90	4		R		1.50	2.90	237.735	459.621
De Blocq van Kuffeler	Gema + Sche	2.33	4.02	13.75	23.75	5	Oranjesluizen → IJmuiden → zee	B	r	13.75	23.75	232.9594	402.3844
Smeenge	Gema + Sche	1.68	2.90	27.50	47.50	6	Afsluitdijk → zee	b	r	27.50	47.50	167.7308	289.7168
Vissering	Gema + Sche	1.58	2.74	13.75	23.75	7	Afsluitdijk → zee	B	r	13.75	23.75	158.4124	273.6214
Wortman	Gema + Sche	1.40	2.41	13.75	23.75	8	Oranjesluizen → IJmuiden → zee	B	r	13.75	23.75	139.7756	241.4306
Krammersluizen	Sche	1.29	2.32	50.00	90.00	9		R		50.00	90.00	128.8208	231.8775
Volkeraksluizen	Sche	1.29	2.32	50.00	90.00	9	Krammerssluizen -> zee Bathse spuisluis → zee Bergse Diepsluis → zee	R		50.00	90.00	128.8208	231.8775
De Ruiter	**Gema+Sche**	1.60	1.92	20.50	24.50	11	IJmuiden → zee scheepssluis Muiden Oranjesluizen → IJmuiden → zee	B	r	20.50	24.50	160.31	191.59
Waterwolf Electra	**Gema+Keer**	1.26	2.26	16.50	29.70	12	Sluizen Zoutkamp → Lauwersmeer	B	r	16.50	29.70	125.73	226.314
Amerongen (Nederrijn)	Wkc+Stuw+Vist+Sche	1.44	1.44	16.00	16.00	12	Hagestein → zee	W	r	16.00	16.00	143.68	143.68
Buma	Gema + Sche	1.21	2.09	13.75	23.75	14	Afsluitdijk → zee	B	r	13.75	23.75	121.1389	209.2399
Leeghwater	Gema	1.32	1.32	30.00	30.00	15	Katwijk → zee Halfweg → IJmuiden → zee Spaarndam → IJmuiden → zee	B	r	30.00	30.00	132.3	132.3
Colijn	Gema + Sche	1.12	1.93	13.75	23.75	16	Roggebotsluis → Afsluitdijk → zee (of via zuidelijke kant)	B	r	13.75	23.75	111.8205	193.1445
Roptazijl	Gema	1.29	1.29	50.00	50.00	16		B	z	50.00	50.00	128.5	128.5
Zwarte Haan	Gema	1.29	1.29	50.00	50.00	16		B	z	50.00	50.00	128.5	128.5
Lovink	Gema + Sche	0.84	1.45	13.75	23.75	19	Afsluitdijk → zee	B	r	13.75	23.75	83.86538	144.8584
Helsdeur	**Gema+Spui+Sche**	0.41	1.99	5.70	27.60	20		B	z	5.70	27.60	41.04	198.72
Ezumazijl	**Gema+Sche**	1.05	1.26	41.00	49.00	21	Lauwerssluizen → zee	B	r	41.00	49.00	105.37	125.93
De Drie Delfzijlen	**Gema+Spui**	0.33	1.63	14.25	71.25	22		B	z	14.25	71.25	32.6325	163.1625
Stavoren	**Gema+Sche**	0.57	0.98	3.30	5.70	22	Afsluitdijk → zee	B	r	3.30	5.70	56.661	97.869
Gouda	Gema	0.69	0.69	25.00	25.00	22	Nieuwe Waterweg → zee	B	r	10.00	10.00	27.6	27.6
Spiegelpolder	**Gema+Sche**	0.60	0.72	20.50	24.50	25	IJmuiden → zee scheepssluis Muiden Oranjesluizen → IJmuiden → zee	B	r	20.50	24.50	60.065	71.785
Schilthuis	Gema	0.60	0.60	30.00	30.00	26	Nieuwe Waterweg → zee	B	r	30.00	30.00	60.3	60.3
Mijndense Sluis	**Gema+Sche**	0.52	0.62	8.20	9.80	27	IJmuiden → zee scheepssluis Muiden Oranjesluizen → IJmuiden → zee	B	r	8.20	9.80	52.07	62.23
Leemans	Gema	0.45	0.45	25.00	25.00	28		B	z	10.00	10.00	18	18
Vier Koggen	Gema	0.40	0.40	25.00	25.00	29	Afsluitdijk → zee	B	r	25.00	25.00	39.5	39.5
Verdoold	Gema	0.36	0.36	25.00	25.00	30	Nieuwe Waterweg → zee	B	r	11.00	11.00	15.95	15.95
Johan Veurink	Gema	0.35	0.35	50.00	50.00	31	Nieuwe Waterweg → zee	B	r	50.00	50.00	34.5	34.5
Abraham Kroes	**Gema+Sche**	0.18	0.59	8.40	27.60	32	Nieuwe Waterweg → zee	B	r	8.40	27.60	17.976	59.064
Altena	Gema	0.29	0.29	50.00	50.00	33	Nieuwe Waterweg → zee Haringvliet → zee	B	r	50.00	50.00	28.5	28.5
Grootslag	Gema	0.28	0.28	25.00	25.00	34	Afsluitdijk → zee	B	r	25.00	25.00	28.25	28.25
Spijksterpompen	Gema	0.27	0.27	30.00	30.00	35		B	z	30.00	30.00	27.3	27.3
Zaayer	Gema	0.26	0.26	30.00	30.00	36	Nieuwe Waterweg → zee	B	r	30.00	30.00	25.8	25.8
Halfweg	Gema	0.21	0.21	4.00	4.00	37	IJmuiden → zee	B	r	4.00	4.00	20.96	20.96
Zedemuden	**Gema+Keer+Sche**	0.10	0.58	2.50	14.00	38	Afsluitdijk → zee	B	r	2.50	14.00	10.4	58.24
Hagestein (Lek)	Wkc+Stuw+Vist+Sche	0.00	0.91	0.00	10.00	39	Nieuwe Waterweg → zee Haringvliet → zee	W		0.00	10.00	0	90.7
Termunterzijl	**Gema+Spui+Sche**	0.17	0.19	27.30	30.00	40		B	z	27.30	30.00	17.472	19.2
Noordpolderzijl	Gema	0.18	0.18	30.00	30.00	40		B	z	30.00	30.00	18.3	18.3
Duurswolde	**Gema+Spui**	0.07	0.34	9.50	47.50	42		B	z	9.50	47.50	6.745	33.725
Lely	Gema	0.17	0.17	25.00	25.00	42	Afsluitdijk → zee	B	z	25.00	25.00	17	17
Westland	Gema	0.17	0.17	30.00	30.00	42	Nieuwe Waterweg → zee	B	z	10.00	10.00	5.6	5.6
Krimpernerwaard	Gema	0.17	0.17	30.00	30.00	42	Nieuwe Waterweg → zee	B	z	30.00	30.00	16.5	16.5
Lemmer (Wouda)	**Gema+Sche**	0.12	0.20	13.75	23.75	46	Afsluitdijk → zee	B	z	13.75	23.75	11.825	20.425
Bergse Diep Sluis	Sche	0.10	0.19	50.00	90.00	47		R		20.00	90.00	4.122266	18.5502
Schermersluis	Sche	0.05	0.21	20.00	90.00	48	IJmuiden → zee	B	r	20.00	50.00	4.6	11.5
Katwijk	Gema	0.15	0.15	1.00	1.00	49		B	z	1.00	1.00	14.61	14.61
Hollands-Duits	Gema	0.14	0.14	25.00	25.00	50	Nieuwe Waterweg → zee Haringvliet → zee	B	r	25.00	25.00	14.25	14.25
Schouten	Gema	0.12	0.12	30.00	30.00	51	Nieuwe Waterweg → zee	B	r	30.00	30.00	12	12
Haandrik	WKC+Stuw+Vist	0.09	0.09	17.00	17.00	52	Afsluitdijk → zee	B	r	17.00	17.00	8.5	8.5
Kadoelen	Gema	0.05	0.05	8.00	8.00	53	IJmuiden → zee	B	r	8.00	8.00	5.44	5.44
Schiegemaal	**Gema+Sche**	0.03	0.05	16.50	28.50	54	Nieuwe Waterweg → zee	B	r	10.00	10.00	1.8	1.8
Spaarndam	**Gema+Sche**	0.01	0.05	0.28	0.92	55	IJmuiden → zee	B	r	0.28	0.92	1.3888	4.5632
J.U. Smit	Gema	0.03	0.03	4.00	4.00	56	Nieuwe Waterweg → zee	B	r	4.00	4.00	3.28	3.28
Zaangemaal	**Gema+Sche**	0.01	0.02	0.28	0.92	57	IJmuiden → zee	B	r	0.28	0.92	0.756	2.484
De Waker	Gema	0.00	0.00	2.00	2.00	58	IJmuiden → zee	B	r	2.00	2.00	0.46	0.46
Overtoom	**Gema+Sche**	0.00	0.00	1.12	3.68	59	IJmuiden → zee	B	r	1.12	3.68	0.0224	0.0736
Oostoever	Spui	0.00	0.00	0.00	0.00	60		B	z	0.00	0.00	0	0
Delfzijl	Spui+Sche	0.00	0.00	0.00	0.00	60		B	z	0.00	0.00	0	0
Nieuw Statenzijl	Spui+Sche	0.00	0.00	0.00	0.00	60		B	z	0.00	0.00	0	0
Lauwerssluizen	Spui+Sche	0.00	0.00	0.00	0.00	60		B	z	0.00	0.00	0	0
Aflsuitdijk Kornwerderzand	Spui+Schee	0.00	0.00	0.00	0.00	60		R		0.00	0.00	0	0
Afsluitdijk Den Oever	Spui+Schee	0.00	0.00	0.00	0.00	60		R		0.00	0.00	0	0
Bathse spuisluis	Spui	0.00	0.00	0.00	0.00	60		R		0.00	0.00	0	0
Haringvliet-sluizen	Spui+Sche	0.00	0.00	0.00	0.00	60		R		0.00	0.00	0	0
Houtrib-sluizen	Spui+Sche	0.00	0.00	0.00	0.00	60	Afsluitdijk → zee	R		0.00	0.00	0	0
Krabbersgat-sluizen	Spui+Sche	0.00	0.00	0.00	0.00	60	Afsluitdijk → zee	R		0.00	0.00	0	0
Nieuwe Waterweg		0.00	0.00	0.00	0.00	60		R		0.00	0.00	0	0
Oranjesluizen	Spui+Sche+Vist	0.00	0.00	0.00	0.00	60	IJmuiden → zee	R		0.00	0.00	0	0
Terneuzen	Sche	0.00	0.00	0.00	0.00	60		R		0.00	0.00	0	0
Dokkumer Nieuwe Zijlen	Spui+Sche	0.00	0.00	0.00	0.00	60	Lauwerssluizen → zee	B	r	0.00	0.00	0	0
Harlingen	Spui+Sche	0.00	0.00	0.00	0.00	60		B	z	0.00	0.00	0	0

References Appendices

Denayer B. & C. Belpaire, 1992. Onderzoek naar de effecten van een vijzelgemaal op vispopulaties. Instituut voor Bosbouw en Wildbeheer van het Ministerie van de Vlaamse Gemeenschap.

Germonpré, E., Denayer, B., Belpaire, C. en Ollevier, F. (1994). Inventarisatie van pompgemalen in het vlaamse gewest en preliminair onderzoek naar schade van diverse pomptypes op vissen na gedwongen blootstelling. Rapporten van het instituut voor bosbouw.

INBO Fishing mortality caused by pumping stations; focus on European Eel, presentation.

Kibel, P. (2008) Archimedes Screw Turbine Fisheries Assessment. Phase II: Eels and Kelts.

Klinge, M., 2008. Evaluatie van de gemaalvispassage in gemaal Meerweg te Haren. Rapport Witteveen+Bos in opdracht van Waterschap Hunze en Aa's.

Koopmans, M., 2013. Monitoring vismigratie bij 14 kunstwerken in het beheergebied van Wetterskip Fryslân, Najaar 2012. A&W-rapport 1863

Kroes, M. & De Boer, M., 2013. Evaluatie stroboscooplampen en FishTrack bij gemaal Offerhaus. Rapport TAUW in opdracht van de CvB.

M.J. Kroes, J.C.A. Merkx & J.H. Kemper, 2006. In- en uittrek van aal en schubvis in het gebied van Noordwest Overijssel. VisAdvies BV, Utrecht. Projectnummer KO2004_008, 36 pag.

Kroon, J.W. & A.N. van Wijk, 2012. Monitoring vismigratieknelpunten 2011; Voor- en najaarsbemonstering bij diverse sluizen en gemalen, VSN2011.01. Visserij Service Nederland in opdracht van Hoogheemraadschap Hollands Noorderkwartier.

Kroon, J.W. & A.N. van Wijk, 2013. Monitoring vismigratieknelpunten 2012; Voor- en najaarsbemonstering bij diverse sluizen en gemalen, VSN2012.02. Visserij Service Nederland in opdracht van Stichting Waterproef

Kruitwagen, G., & M. Klinge, 2007. Monitoring van stroomafwaartse migratie van vis bij gemaal Katwijk. Rapport Witteveen+Bos i.o.v. Hoogheemraadschap van Rijnland.

Kruitwagen, G., Klinge, M., 2008a. Sterfte van schieraal door gemaal IJmuiden, onderzoeksjaar 2008, idem 2009. Rapport Witteveen+Bos in opdracht van Rijkswaterstaat Noord-Holland.

Kruitwagen, G. & M. Klinge, 2008b. Stroomafwaartse passage van vis via gemaal Schoute. Rapport Witteveen+Bos i.o.v. 's Gravenhaagse Hengelsport Vereniging.

Kruitwagen, G. & M. Klinge, 2008c. Monitoring van stroomafwaartse migratie van vis bij de gemalen Halfweg, Spaarndam en Gouda. Rapport Witteveen+Bos i.o.v. Hoogheemraadschap van Rijnland.

Kruitwagen, G., Klinge, M., 2010a. Monitoring van vismigratie bij gemaal J.L. Hoogland en de Johan Friso-sluis. Rapport Witteveen+Bos in opdracht van wetterskip Fryslân.

Kruitwagen, G., Klinge, M., 2010b. Monitoring van vismigratie bij 4 potentiële migratieknelpunten voor- en najaarsonderzoek 2009. Rapport Witteveen+Bos in opdracht van het Hoogheemraadschap van Schieland en de Krimpenerwaard.

Kruitwagen, G., Klinge, M., 2010c. Monitoring van vismigratie bij de gemalen Hoekpolder en Aalkeetbuitenpolder Najaarsonderzoek 2009. Rapport Witteveen+Bos in opdracht van het Hoogheemraadschap van Delfland

Patrick, P. H., & Mckinley, R. S. (1987) Field evaluation of a Hidrostal pump for live transfer of American eels at a hydroelectric facility. North American Journal of Fisheries Management 7, 303- 305.

Riemersma, P. & G.J.M. Wintermans, 2005. Optimalisatie vismigratie Den Deel, najaarsonderzoek. Onderzoek naar mogelijkheden inzet scheepvaartsluis ter bevordering van vismigratie bij gemaal Den Deel. Grontmij Noord BV en Wintermans Ecologenbureau.

Spah, H., 2001. Fishery biological opinion of the fish compatibility of the patented hydraulic screw from Ritz Atro. Bielfield, Germany

Vis H., Q.A.A. de Bruijn & J.H. Kemper, 2013. Onderzoek naar de visoverleefbaarheid bij vijzelgemaal Ennemaborgh op 23 oktober 2012. Projectnummr VA2012_25, 22 pag.

VisserijServiceNederland, 2010. Onderzoek najaarsmigratie van vis 2010 naar het Noordzeekanaal vanuit het beheergebied van hoogheemraadschap Hollands Noorderkwartier.

Vriese, F.T. (VisAdvies), 2009. Onderzoek naar de visveilige axiaalpomp en buisvijzel. VisAdvies BV, Nieuwegein. Projectnummer VA2009_19, 24 pag.

Vriese, F.T., 2010. Nulmeting schadeprofiel gemaal Offerhaus. VisAdvies BV, Nieuwegein. Projectnummer VA2009_45, 31 pag. + bijlage.

Vriese FT, Hop J, Kampen J., 2010. Gemalen en schade aan vis. VisAdvies BV, Nieuwegein. Projectnummer VA2009_33, pp. 145.

Wanink, J., Bonhof, G.H., Bouton, N., Slabbekoorn, H., 2012. Project vissen zwemmen weer heen en weer: vismonitoring en geluidsmetingen, najaar 2011

Winter, H.V., Griffioen, A.B., van de Wolfshaar, K.E. (2013a) Inventarisatie van de belangrijkste knelpunten voor de uittrek van schieraal in Nederland. IJmuiden. IMARES, (Rapport / IMARES C107/13) - p. 50

Winter HV, Griffioen AB, van de Wolfshaar KE. (2013b). Knelpunten inventarisatie voor de uittrek van schieraal t.b.v. 'Paling Over De Dijk'. IMARES-report C134/13.