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Report of the Workshop on Eel Stocking (WKSTOCKEEL)

20–24 June 2016

Toomebridge, Northern Ireland, UK

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CIEM Conseil International pour l'Exploration de la Mer

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Executive summary

The ICES Workshop on Eel Stocking (WKSTOCKEEL), chaired by Derek Evans, UK, met in Toomebridge, N. Ireland, UK, 20–24 June 2016. This workshop was convened to update knowledge on the net benefit of stocking (the practice of adding eels to a waterbody (*recipient*) from another source (*donor*)), to the recovery of the eel stock, and to make proposals for research to fill any crucial knowledge gaps that prevent a definitive advice on stocking as a stock conservation measure. The definition of net benefit of stocking was taken as "where the stocking results in a higher silver eel escapement biomass than would have occurred if the glass eel seed had not been removed from its natural (donor) habitat in the first place". Nineteen EU experts participated in the meeting, representing 6 countries. ICES has repeatedly reviewed the issues surrounding capture, transfer and stocking of European eel, almost as a standing item on its annual agenda. The most recent (2015) advice reiterates many previous conclusions. It includes evidence that translocated and stocked eel can contribute to yellow and silver eel production in recipient waters, (but that evidence of contribution to actual spawning is limited by the lack of knowledge of the spawning of any eel) and that Internationally coordinated research is required to determine the net benefit of stocking on the overall population, (including carrying capacity estimates of glass eel donor estuaries as well as detailed mortality estimates at each step of the stocking process).

The use of stocking is listed in the EU Eel Regulation 1100/2007 as one of a range of management measures that could feature in an Eel Management Plan, and as such be eligible for grant support from the European Fisheries Fund. By 2013 stocking of glass eel was undertaken in 16 Member States. Whilst stocking is a measure featuring in many EMPs, only six achieved their EMP stocking target.

The conclusions from WKSTOCKEEL echo many of those from the most recent reviews and the latest advice and recommendations from ICES (2015) given that many of their concerns remain un- addressed. Studies were found to lack controls and/or a simultaneous assessment of the life history of those glass eel left *in situ*. This in effect means that, whilst a local benefit may be apparent, an assessment of net benefit to the wider eel stock is unquantifiable. For the (lifetime) natural mortality, there is little information available, and no reporting obligations. The contribution of stocking derived silver eel to the spawning stock is still not quantifiable and is limited by the lack of knowledge on the spawning of *any* eel.

As a consequence of the above conclusions, the knowledge base for the assessment of the net-benefit of stocking is extremely weak. Until such research needs to address the knowledge gaps have been undertaken, there is no basis for the evaluation of individual stocking cases. Such research needs identified included carrying capacity estimates of glass eel donor systems, lifetime mortality estimates, mortality estimates within commercial stocked eel trade channels and the observation and origin assessment of silver eel spawning in their natural environment.

Extended summary

Current Eel Stock

The life history and biology of the European eel is recognised for its complex nature, a synopsis of which is given in Annex 1, and an associated glossary of terms used in it and this report provided in Annex 2.

The most recent assessment of the European eel's status (ICES, 2015) states that the overall stock decline continues and all anthropogenic mortality (e.g. recreational and commercial fishing on all stages, hydropower, pumping stations, and pollution) affecting production and escapement of silver eels should be reduced to – or kept as close to – zero as possible. The status of eel remains critical.

Overall glass eel recruitment has fallen to 8.4% of the 1960–1979 average in the "elsewhere Europe" series and to 1.2% in the North Sea series. It shows little sign of recovery. As a consequence, the abundance of young yellow eel in many areas has also declined.

In 2007, European eel was included in CITES Appendix II that deals with species not necessarily threatened with extinction, but for which trade must be controlled if it is necessary to avoid utilization incompatible with the survival of the species. The European eel was listed in September 2008 as 'critically endangered' in the IUCN Red List (IUCN Red List website).

In response to scientific advice and stakeholders' concerns about the declining stock, the European Commission established a management framework in 2007 through an Eel Recovery Plan (ERP: EC Regulation EU COM 1100/2007; "Establishing measures for the recovery of the stock of European eel": EC, 2007), with the objectives of protection, recovery and sustainable use of the stock. To achieve these objectives, Member States have an obligation to develop eel management plans (EMPs) for each of their river basin districts (RBD). The objective of the national EMPs is to provide, with high probability, a long-term escapement to the sea of the biomass of silver eel equivalent to 40% of the best estimate of the theoretical escapement in pristine conditions (i.e. if the stock had been completely free of anthropogenic influences).

The Use and outcomes of Stocking

Stocking or translocation (formerly called restocking) is the practice of adding eels to a waterbody **(*recipient*)** from another source (***donor***), to supplement existing populations or to create a population where none exists.

Since 1840, attempts have been made to redistribute young eel from the areas of highest abundance to other countries and farther inland. This 'restocking' has been troubled by technical constraints (e.g. mode of transport and maximum distance eel can be shipped alive), wars (e.g. the Franco–Prussian War and World Wars One and Two) and, in recent decades, by shortage of supply due to the general decline of the eel stock all across Europe (Dekker & Beaulaton, 2016).

Glass eel fisheries are undertaken across the EU (UK, France, Spain and Portugal being the main fisheries) using a wide variety of gears, and fishing methods (ICES, 2012; Briand *et al.*, 2012). In 2008 prior to the inception of EMP's in 2009, twelve countries proposed the use of stocking in their management plans to enhance eel populations (ICES, 2008). At this time ICES reported on a perceived stocking requirement of approximately 40t to fulfil reported EU needs.

By 2013 stocking of glass eel was undertaken in 16 Member States. Whilst stocking is a measure featuring in many EMPs, only six achieved their EMP stocking target. Most EMU's had undertaken a limited quantity of their stocking targets while a few had yet to implement any of their stocking actions (ICES, 2013b).

The most common reason given in 2013 for a country being unable to achieve its stocking target was a lack of funding to buy glass eel, which was different from that given in the recent past when the cost of glass eel was given as the cause. More recently the availability of glass eel for stocking was highlighted as being restrictive.

Stocking methods

WGEEL reports (ICES, 2006; 2007; 2008; 2009 & 2011) have commented extensively on stocking theory and guidelines for "good practice" approaches to stocking, based on a variety of published reports and manuals (Williams and Aprahamian, 2004; Symonds, 2006; Williams and Threader, 2007, Environment Agency, 2010). Stocking parameters such as temperature, stocking location, stocking densities, local ecological considerations etc are included in these guidelines.

Outcomes of stocking

The outcome of stocking has been evaluated by ICES in 2006, 2008, 2009 and 2011 from WGEEL reports and it was clear from local studies that stocking had been beneficial by enhancing the yellow and silver eel stocks in a number of water bodies. These included several Danish, German, Swedish and Estonian Lakes, Lough Neagh in Northern Ireland as well as Danish streams and marine areas.

The benefit of stocking can be considered at three geo-political scales:

- local interests (the production gained locally by stocking);
- the national/EMU scale of Eel Management Plans (applying stocking to achieve EMP biomass targets);
- the continent-wide scale (stocking contributing to the general recovery of the stock).

Definition of Net Benefit

For the purposes of this Workshop, and as outlined in the Scientific Justification distributed with the Workshop's Terms of Reference, the definition of ***net benefit*** of stocking is taken as:

"where the stocking results in a higher silver eel escapement biomass than would have occurred if the glass eel seed had not been removed from its natural (donor) habitat in the first place".

The Workshop noted that the ToR did not request the provision of a qualitative judgement or advice on the use of stocking, and propose that this should be directed to an appropriate fora such as WGEEL.

There is ample evidence that the release of additional young eels in a water body contributes to the abundance of eel, (production and yield), creating an increased escapement of silver eels from the recipient waterbody – the benefit. From the aspect of the donor habitat, the use of glass eel for stocking can either compete with the demand for other uses (direct consumption, aquaculture), or create an increase in demand, leading to an increased exploitation rate in the donor area. Hence, the use of glass eel for stocking can either be contrasted to other uses (option A in Figure i), or to a reduction in exploitation rate of glass eel in the donor area (option B).

In earlier reports (ICES 2011), option A has been considered, interpreting the net-benefit as the increased production due to stocking, minus the loss of production due to anthropogenic mortality in the recipient area – this approach assumes that the glass eel would have been harvested anyway.

Giving priority to the recovery of the European stock, this led to the recommendation that, the objective of any stocking exercise should be to maximize net benefit to the stock as a whole, i.e. the glass eel be released into areas of lowest anthropogenic mortality.

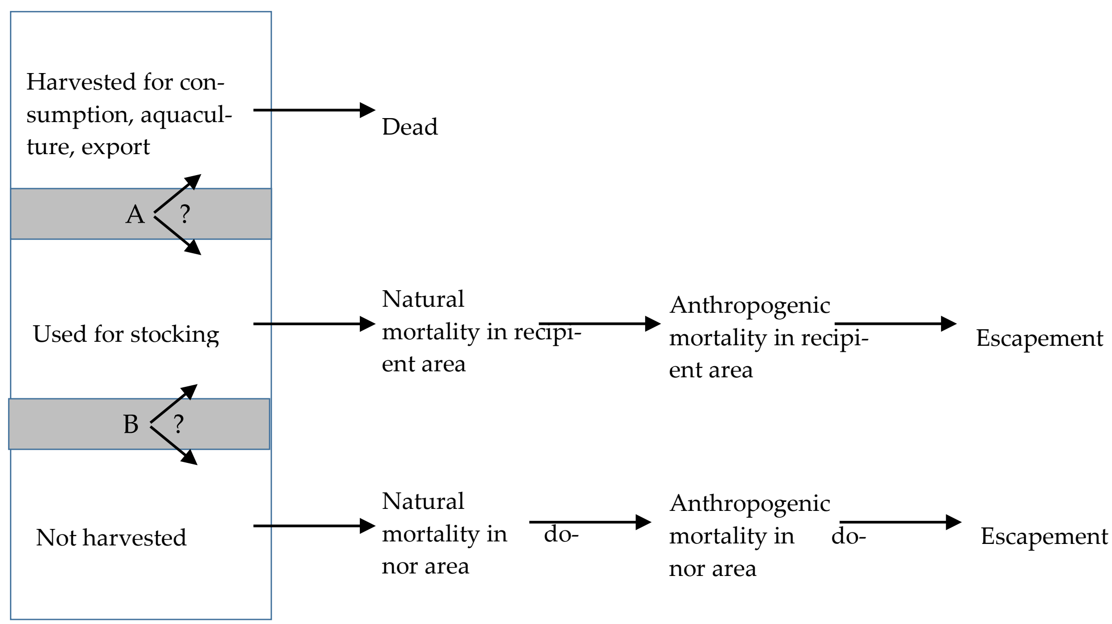

Figure i. Diagram of the alternative uses of glass eel from the donor area.

Chapter 5 of this report explores option B, using a range of scenarios and interpreting the net-benefit as the increase of production in the recipient area, minus the loss of production in the donor area – (assuming that the demand for stocking has led to an increased exploitation rate in the donor area, or alternatively, that a reduction in the glass eel demand for stocking results in a lower exploitation rate in the donor area). Only marginal effects are analysed since the effects of any ban on stocking or other exploitation are much more unpredictable.

Stocking and the Eel Recovery Regulation 1100/2007

During the creation of the Eel Regulation in 2007 the Council of the European Union noted that in relation to eel there are diverse conditions and needs throughout the Community which will require different specific solutions or management actions.

To that effect Article 2(8) of the 2007 Eel regulation 1100/2007 stated that:

(8) An Eel Management Plan may contain but is not limited to, the following measures:

- Reducing commercial fishing activity
- Restricting recreational fishing
- **Restocking measures**
- Structural measures to make rivers passable and improve river habitats, together with other environmental measures.
- Transportation of silver eel from inland waters to waters from which they can escape freely to the Sargasso Sea
- Combating predators
- Temporary switching off hydro-electric power turbines
- Measures related to aquaculture

The provision of funding towards the purchase of glass eel for such *restocking me*asures was made available by the EU via grant aid from the European Fisheries Fund (EFF).

In addition to the use of stocking as a management measure Article 7 of the Regulation requires that any Member State that permits fishing for glass eels/elvers (defined as eels < 120 mm total length, used throughout) must reserve at least 35% of the catch for stocking purposes within the EU in the first year of a compulsory EMP (which is assumed to be 2010), increasing by at least 5% per year to achieve at least 60% by 31 July 2013.

Lastly, Article 12 stated that "no later than 1 July 2009, Member States shall take the measures necessary to identify the origin and ensure the traceability of all live eels imported or exported from their territory."

Previous ICES Reviews on Stocking

ICES (ICES, 2006, 2007, 2008. 2009, 2011, 2013a) has repeatedly reviewed the issues surrounding capture, transfer and stocking of European eel, almost as a standing item on its annual agenda. These reviews were originally commissioned with the 1990s view (Moriarty and Dekker ,1997; Watson *et al.*, 1999; Moriarty 1999) that glass eel could be redistributed from European "donor" estuaries with glass eel fisheries, (such as the UK, France, Spain and Portugal) and used to enhance "recipient" fisheries or stocks where recruitment is low, but within the natural range of eel.

The most recent reviews (Pawson, 2012; WGEEL 2011) on the value of stocking state that there are major knowledge gaps to be filled before firm conclusions either way can be drawn. There was almost no new evidence available to Pawson in 2012 that was not considered by ICES in its 2011 report and the conclusions and recommendations of both are similar:

1) Translocated and stocked eel can contribute to yellow and silver eel production in recipient waters, but evidence of their contribution to actual spawning is limited by the general lack of knowledge of the spawning of any eel.
2) In addition to investigations on the value of stocking for the enhancement of silver eel escapement in distinct EMUs, it was recommended that internationally coordinated research is required to judge the net benefit of stocking for the overall population.
3) Assessments of carrying capacity estimates of glass eel donor estuaries are absent.
4) Detailed mortality estimates along glass eel trade channels are required.
5) The impact of holding and maintenance feeding of elvers in aquaculture with regard to a possible adaptation to culture conditions (as known from other fish species like salmon and trout) is unknown.
6) Ongrown eels exhibit no advantage in growth and survival compared to stocking with glass eel: The only benefits conferred wer allowing temperature conditions to become suitable in the recipient waters, and the facilitation of veterinary observations during quarantine.
7) The most frequent shortfall in early life history mortality and development assessments was the absence of controls in the studies.
8) Analyses of the life histories of those glass eels "left behind" at the donor estuaries is a prerequisite to any net benefit assessment and does not feature in any of the studies reviewed.

ICES Advice in relation to stocking 2015

The most up-to-date stocking advice from ICES (2015) reiterates the main conclusions and recommendations from so many previous reviews:

- ICES notes that stocking of eels is a management action in many eel management plans, and that this stocking is wholly reliant upon a glass eel fishery catch to provide "seed".
- There is evidence that translocated and stocked eel can contribute to yellow and silver eel production in recipient waters, but evidence of contribution to actual spawning is limited by the lack of knowledge of the spawning of any eel.
- Internationally coordinated research is required to determine the net benefit of stocking on the overall population, including carrying capacity estimates of glass eel donor estuaries as well as detailed mortality estimates at each step of the stocking process.
- When stocking to increase silver eel escapement and thus aid stock recovery, an estimation of the prospective net benefit should be made prior to any stocking activity.
- Where eel are translocated and stocked, batch marking to distinguish between groups recovered in later surveys should be undertaken to evaluate their fate and their contribution to silver eel escapement.

Eighteen EU experts attended the meeting, representing 6 countries. One representative of the EU Commission DG MARE attended as a participant.

Terms of Reference

The Workshop was tasked by ICES to consider the following terms of reference (ToR):

a) Review and consider recent research into the net benefit of stocking eel for contributing to the spawning stock, including updating recent reviews (including ICES 2013 & Pawson 2012) and prepare a review paper for a scientific journal if appropriate;

b) Identify knowledge gaps currently preventing a definitive determination of the net benefit of eel stocking (see a), and prioritise these gaps in terms of their impact on the uncertainty of net benefit;

c) Design approaches to address the highest priority knowledge gaps (b), including methods, expertise and situations required, and identify potential funding mechanisms;

d) Draft proposals for funding support to address these highest priority knowledge gaps (c).

Capture of stocking "seed" and its associated mortalities

The origin of the stocked eels is an important consideration and can have a significant impact on their subsequent survival, growth and ultimately their contribution to escaping silver eel biomass.

ICES recognises that stocking is wholly reliant upon this glass eel harvest to provide such "seed" and that any net benefit from stocking must consider what would have occurred if that seed had not been removed from its natural habitat in the first place. This infers the need for an understanding of natural mortality and life history development at such donor sites against which stocking "associated" mortality and subsequent stocked eel performance can be compared.

Given that glass eel from the European eel cannot be produced artificially, stocking materials can only be obtained by catching eels in the wild. ICES (2008 & 2011) have repeatedly recommended specific considerations prior to the capture of a decreasing glass eel resource for use in stocking:

- A demonstrable surplus should exist within donor glass eel stocks (i.e. those donor EMUs will still achieve their conservation target having removed a component of their recruitment)
- The mortality of recruits from donor estuaries used in stocking must be taken into account.
- Anthropogenic mortality in the recipient areas is minimized

There is a belief that density dependent mortality on glass eel and elvers will be at such levels under conditions of high recruitment that many of the recruits would die of natural mortality causes and therefore, fishing is only taking eels from that 'surplus' and so has little effect on recruitment into the 'growth stage' population. Furthermore, that recruitment overfishing could be counterbalanced by the use of 'excess' glass eel in restocking (Moriarty & Dekker, 1997).

However, although this approach is biologically sound, there appears to be little or no scientific evidence to support it for eels.

The mortality incurred by harvested glass eel is not solely limited to the point of capture, but can occur across the range of post-fishing activities that comprise the chain of events involved in stocking such as handling, aquaculture facility retention (extended quarantine), transportation, and actual stocking.

WKSTOCKEEL concluded that in relation to mortalities of glass eel it was difficult to find any data that was directly linked to commercial stocking operations. For other aspects (e.g. performance of stocked eel) the published data showed a wide range of results with in many cases no factors listed which may explain these variations.

Whilst the daily natural mortality at the glass eel stage is considered to be of the order of magnitude of 0.01, there is enormous variation across EU anthropogenic mortalities ranging from close to 0 – 4.

All of these ranges and uncertainties make it difficult for an accurate (or at best realistic) contribution of a donor mortality estimate into any calculation of net benefit.

Risks involved in stocking

Precautionary principles

ICES has previously advised that a precautionary approach should be applied in assessing risk when the outcome of stocking is uncertain (ICES, 2006, 2007, 2008. 2009, 2011).

Definitions of the precautionary approach as used in relation to fisheries generally start from the standpoint of ***not delaying action*** [to protect stocks] ***where there is uncertainty that the action will succeed.*** However, the lack of any data found in numerous previous reviews on the ultimate fate of either stocked versus natural immigrants throws up a long list of 'what if' scenarios all of which carry with them similar associated risks.

The risks involved in stocking have been discussed at length by ICES, but most notably (ICES, 2011; 2013), with a particular focus on the amount of stocked eel being used throughout Europe and its associated trade (ICES, 2013). All of these were revisited by WKSTOCKEEL and concluded that:

- *Capture & Handling Mortality:* some glass eel fisheries and their associated gears impart significant mortality and post-capture stress while other gear types and methods are relatively benign.
- *Genetics:* The European and North American Eel stocks are both considered strongly panmictic. Stocking eels between catchments and countries within the species natural range appears to present a low risk to genetic integrity.
- *Migration:* There is strong evidence that silver eels derived from stocking, mature, migrate and navigate in a similar fashion to native origin eel.
- *Biosecurity:* The spread of non-native invasive species, including parasites and pathogens, poses an additional threat to the ecology of the recipient catch-

ments but can be avoided or reduced by the application of robust biosecurity protocols currently in use as demonstrated by long term stocking programmes in the UK and Sweden.

- *Eel Quality:* Stocking should avoid areas known to impact on the quality of eel through contaminants, and/or pathogens. Low Eel quality is likely to impair migration, spawning success and the viability of offspring. Differences in eel quality has not been quantified for silver eel derived from either native or stocked glass eels.
- *Growth & Survival:* Stocking young eel is known to increase yellow eel stocks. Ongrown eels exhibit no advantage in growth and survival compared to stocking with glass eel whilst stage stocked is not likely to influence their future survival and silvering rate.

  Differences in growth vary although most studies indicate little difference between stocked and wild origin
- *Sex Differentiation:* This appears to be hugely variable and easy to manipulate. Stocking is likely to increase the proportion of males, by altering (increasing) overall eel density.
- *Aquaculture:* The only benefits conferred were allowing temperature conditions to become suitable in the recipient waters prior to stocking and veterinary screening during quarantine.

Monitoring methods for the evaluation of stocking and associated knowledge gaps

Monitoring is of key importance when trying to investigate highly mobile and long lived animals such as migratory fish species. For eel, many questions remain poorly understood as a consequence of insufficient monitoring, such as the impact of stocking on the survival of various life stages at both the donor and the recipient waterbody, However, the development and implementation of robust monitoring programmes has lead to an understanding of the migration patterns of silver eels emanating from previously stocked eel (Westerburg *et al*., 2014). As such, monitoring methods are the only way to assess the efficiency and contribution of a management action based around stocking.

Definition of the life stages used in stocking is often ambiguous and with this their life history prior to stocking. As discussed previously this has implications for assessing survival and growth in each stocking situation, any subsequent stock benefit analyses derived from these assessments and brings with it the need for a range of monitoring methodologies.

ICES have consistently recommended that where eel are translocated and stocked, measures should be taken to evaluate their survival rate and contribution to silver eel escapement. This requires international coordination undertaking batch marking of eel to distinguish groups recovered in later surveys (e.g. recent Swedish, French, and UK marking programmes).

Quantitative assessment of the net mortality and survival in the continental stage has been deemed a necessity (WGEEL, 2013). Calculation of mortality and survival, particularly for young life stages, have been assumed from empirical knowledge. For instance, the natural mortality used in the back-calculation of larger eels into glass eel equivalents applies to eels in natural habitats yet the French EDA model includes an additional 20% survival from the glass eel to the yellow eel stage (ICES, 2013). According to French expertise (ICES, 2015), early life stage survival post-stocking depends on numerous factors related to the environment and to the stocking itself as discussed previously.

There have been some encouraging reports of contributions of stocked eels to fisheries which have reported survival rates for elvers ranging from 3.5 to 20% (Shiao *et al*., 2006; Pedersen, 1998; Andersson and Sanstrom, 1992) and a survival rate of up to 80% for yellow eels (McCarthy *et al*., 1996).

In short, there have been a significant number of studies examining the outcomes of stocking and these have provided ample evidence that translocated and stocked eel contribute to yellow and silver eel production in recipient waters.

As noted so frequently in this report the lack of any controls used in these studies or a simultaneous assessment of the life history of those glass eel "left behind" at the donor site means that, while a local benefit may be apparent, an assessment of net benefit to the wider eel stock is unquantifiable.

Current research on wild and stocked eel outcomes

In order to fill this knowledge gap, a study is currently underway on the Oir river, France, to experimentally evaluate and compare survival rates of glass eels from natural and stocked origin during their first few months. The Workshop notes that this is the only known project of its kind and directly addresses the shortfalls noted above and the recommendations from ICES WGEEL (ICES, 2006, 2007, 2008. 2009, 2011, 2013a). The project aims to compare the stocking protocol used in Europe and to set up an experiment to study the early stage (3 month) survival of both natural and stocked glass eel from the same donor habitat.

Contribution of stocked eel to spawning

In addition to the larger tagging methods described above, several other methods have been designed aimed at tracking larger eel movements in detail, irrespective of being from a stocked or natural origin. Such methods include the use of acoustic tags, radio tags and different kinds of data storage tags (DST). None of these are suitable for small eels as the tags are quite large but they have been used successfully to document the migration of silver eels (from both stocked and wild origin) out of the Baltic (Westerberg *et al*., 2014), and to track the oceanic migration and behaviour of silver eels in the North Atlantic (EELIAD project 2013 Wahlberg *et al*., 2014).

However, none of these studies were able to document the successful migration to the breeding grounds and subsequent spawning of any of the silver eels tagged, let alone discriminate between any differences in these behaviours as a consequence of their origin (from a stocked or wild juvenile eel).

Ultimately the success of a stocking programme will be judged on the ability of resultant silver eels to contribute to future generations.

As found in many previous stocking reviews this contribution is still not quantifiable and is limited by the lack of knowledge on the spawning of any eel.

Assessment of stocking scenarios

Choice of case studies

The eel stock is distributed over a myriad of habitats across its range with local characteristics (habitat, biological parameters) varying over very short ranges. Only a small number of these local situations has been analysed, and results are often hard to compare between habitats and/or cases. Hence we selected a few scenarios based on well-documented case studies. In selecting these case studies, the aim was not to provide a representative cross-section of all habitats, but to provide an adequate overview of the range of potential circumstances available.

Given a total of 6 different sources and 6 different destinations, a total number of 36 scenarios have been evaluated. For each of these scenarios, the rate of change in the silver eel escapement has been estimated. Overall, almost all scenarios appear to result in a net loss in the production of silver eel escapement, except for those scenarios taking their glass eel from areas of high anthropogenic mortality, releasing them into areas of low anthropogenic mortality (unexploited), and inflicting a low handling mortality. In most cases, a reduction of the anthropogenic mortality in the source area might constitute a more direct approach to increase the overall silver eel escapement. Where such a reduction turns out to be unachievable for other reasons, translocation of the young recruits might be an option.

Transporting young recruits across a barrier within a river system (assisted migration) appears to create no net-benefit in any case. However, assisting migration does make habitats available to the eel, and maintains a natural eel population in those habitats. Whether or not access to these habitats will actually increase the net production of silver eel escapement, will need to be proven in each individual case.

Scenario conclusions

The current assessment of the net-benefit of stocking and assisted migration is based on information about case-specific lifetime anthropogenic mortality, while values of natural mortality where synchronised for all sites, and where omitted from net benefit calculations this way.

The routine stock assessments reported every third year to the European Commission provide some information on the anthropogenic mortality allowing a process of (further) scrutinising and standardisation of the estimation process.

For the (lifetime) natural mortality, however, there is generally little information available, and there are no reporting obligations.

As a consequence, the knowledge base for the assessment of the net-benefit of stocking actions is extremely weak.

It is therefore recommended to improve the knowledge on (lifetime) natural mortalities, including its spatial variation and the relation to case-specific (local) conditions.

Until such research has been undertaken, there is no basis for the evaluation of individual stocking cases, other than the general, conservative assessment given here.

Research needs in order to establish the net benefit of stocking

WKSTOCKEEL has reviewed the current relevant literature on eel stocking and this report has been compiled by the leading experts in the field. We note that some former scientific concerns about eel stocking have now been addressed but there are still a range of knowledge gaps.

WKSTOCKEEL recommends that these Research Needs are highlighted to WGEEL in order to progress the design of approaches to examine the highest priority knowledge gaps (including methods, expertise, situations required, and the identification of potential funding mechanisms).

The following are recommended research needs to address the identified knowledge gaps:

Glass eel/elver/juvenile eel

- Assessments of carrying capacity estimates of glass eel donor estuaries are absent; these are fundamental in denoting any "surplus".
- A whole eel distribution approach to assessing, lifetime mortality, stocking and determining net benefit to the stock (such as the current French project (Section 4.4.1)). Studies must incorporate:
    1. i. Appropriate experimental controls;
    2. ii. Evaluation of the mortality of the stocked fish;
    3. iii. Evaluation of the mortality of the cohort left *in situ*;
    4. iv. Development and growth of both cohorts over time.
- Detailed mortality estimates within the commercial stocked eel trade channels.

Silver eel

- Further research into silver eel migration including:
    1. i. Observe and measure actual spawning;
    2. ii. Assess the reproductive fitness and spawning contribution of silver eels from stocking programs and those of native-origin;
    3. iii. Further development of origin identification methods to assist with the above.

Overall Conclusions

The conclusions from this WKSTOCKEEL echo many of those from the most recent reviews by Pawson, (2012) & WGEEL (2011) and reiterate the latest advice and recommendations from ICES (2015) (Section 1.5) given that many of their concerns remain unaddressed.

- There have been a significant number of studies examining the outcomes of stocking and as found previously they provide further evidence that translocated and stocked eel contribute to yellow and silver eel production in recipient waters.

- However as noted previously the studies lack controls and/or a simultaneous assessment of the life history of those glass eel left *in situ*. This in effect means that, whilst a local benefit may be apparent, an assessment of net benefit to the wider eel stock is unquantifiable.
- It was difficult to find any data (on any metric) that was directly linked to commercial stocking operations
- For other aspects (e.g. performance of stocked eel) the published data showed a wide range of results; in many cases no factors were listed which may explain these variations.
- Whilst the natural mortality at the glass eel stage is considered by some to be of the order of magnitude of 0.01, there is enormous variation across EU anthropogenic mortalities ranging from close to zero – 4.
- For the (lifetime) natural mortality, there is generally little information available, and there are no reporting obligations. As a consequence, the knowledge base for the assessment of the net-benefit of stocking actions is extremely weak.
- Ultimately the success of a stocking programme will be judged on the ability of resultant silver eels to contribute to future generations. Whilst concerns over the negotiation of migratory pathways have been reduced the contribution of stocking derived silver eel is still not quantifiable and is limited by the lack of knowledge on the spawning of ***any*** eel.

As a consequence of the above conclusions, the knowledge base for the assessment of the net-benefit of stocking is extremely weak. Until such research needs to address the knowledge gaps have been undertaken, there is no basis for the evaluation of individual stocking cases

1 Background

1.1 Current Eel Stock

The life history and biology of the European eel is recognised for its complex nature, a synopsis of which is given in Annex 1, and an associated glossary of terms used in it and this report provided in Annex 2.

The most recent assessment of the European eel's status (ICES, 2015) states that the overall stock decline continues and all anthropogenic mortality (e.g. recreational and commercial fishing on all stages, hydropower, pumping stations, and pollution) affecting production and escapement of silver eels should be reduced to – or kept as close to – zero as possible. The status of eel remains critical.

Overall glass eel recruitment has fallen to 8.4% of the 1960–1979 average in the "elsewhere Europe" series and to 1.2% in the North Sea series. It shows little sign of recovery. As a consequence, the abundance of young yellow eel in many areas has also declined.

In 2007, European eel was included in CITES Appendix II that deals with species not necessarily threatened with extinction, but for which trade must be controlled if it is necessary to avoid utilization incompatible with the survival of the species. The European eel was listed in September 2008 as 'critically endangered' in the IUCN Red List (IUCN Red List website).

In response to scientific advice and stakeholders' concerns about the declining stock, the European Commission established a management framework in 2007 through an Eel Recovery Plan (ERP: EC Regulation EU COM 1100/2007; "Establishing measures for the recovery of the stock of European eel": EC, 2007), with the objectives of protection, recovery and sustainable use of the stock. To achieve these objectives, Member States have an obligation to develop eel management plans (EMPs) for each of their river basin districts (RBD). The objective of the national EMPs is to provide, with high probability, a long-term escapement to the sea of the biomass of silver eel equivalent to 40% of the best estimate of the theoretical escapement in pristine conditions (i.e. if the stock had been completely free of anthropogenic influences).

1.2 The Use and outcomes of Stocking

Stocking or translocation (formerly called restocking) is the practice of adding eels to a waterbody **(*recipient*)** from another source (***donor***), to supplement existing populations or to create a population where none exists.

Since 1840, attempts have been made to redistribute young eel from the areas of highest abundance to other countries and farther inland. This 'restocking' has been troubled by technical constraints (e.g. mode of transport and maximum distance eel can be shipped alive), wars (e.g. the Franco–Prussian War and World Wars One and Two) and, in recent decades, by shortage of supply due to the general decline of the eel stock all across Europe (Dekker & Beaulaton, 2016).

Glass eel fisheries are undertaken across the EU (UK, France, Spain and Portugal being the main fisheries) using a wide variety of gears, and fishing methods (ICES, 2012; Briand *et al.*, 2012).

In 2008 prior to the inception of EMP's in 2009, twelve countries proposed the use of stocking in their management plans to enhance eel populations (ICES, 2008). At this time ICES reported on a perceived stocking requirement of approximately 40t to fulfil reported EU needs.

By 2013 stocking of glass eel was undertaken in 16 Member States (Figure 1). Whilst stocking is a measure featuring in many EMPs, only six achieved their EMP stocking target. Most EMU's had undertaken a limited quantity of their stocking targets while a few had yet to implement any of their stocking actions (ICES, 2013b).

The most common reason given in 2013 for a country being unable to achieve its stocking target was a lack of funding to buy glass eel, which was different from that given in the recent past when the cost of glass eel was given as the cause. More recently the availability of glass eel for stocking was highlighted as being restrictive.

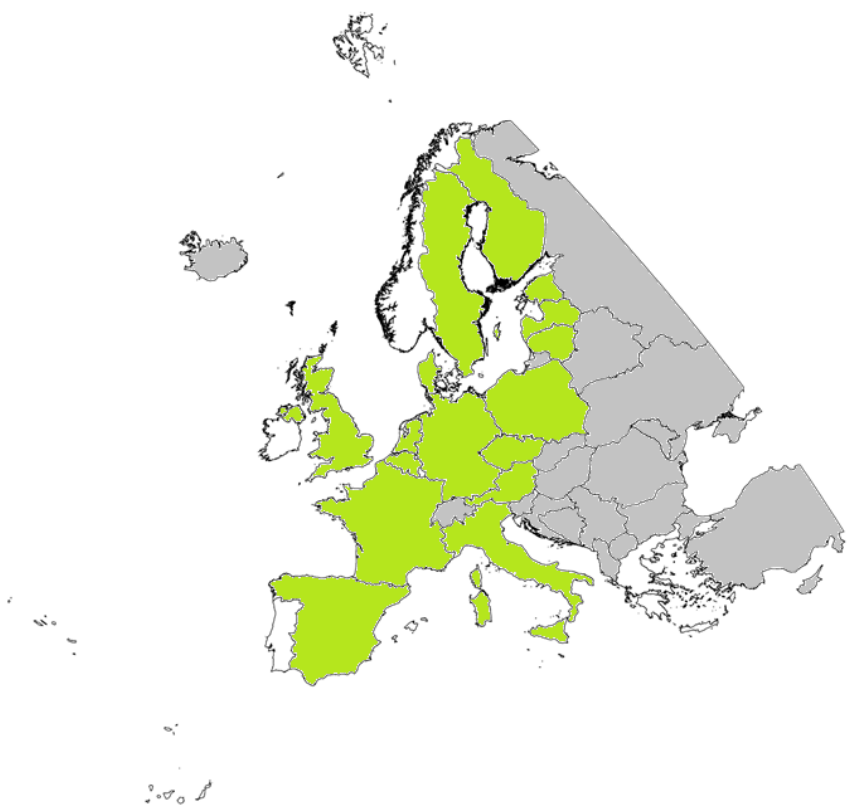

Figure 1. Management measures related to stocking undertaken by country: green = measures either in place or intended; white = no known measures; grey= no data

1.2.1 Stocking methods

WGEEL reports (ICES, 2006; 2007; 2008; 2009 & 2011) have commented extensively on stocking theory and guidelines for "good practice" approaches to stocking, based on a variety of published reports and manuals (Williams and Aprahamian, 2004; Symonds, 2006; Williams and Threader, 2007, Environment Agency, 2010). Stocking parameters such as temperature, stocking location, stocking densities, local ecological considerations etc are included in these guidelines.

1.2.2 Outcomes of stocking

The outcome of stocking has been evaluated by ICES in 2006, 2008, 2009 and 2011 from WGEEL reports and it was clear from local studies that stocking had been beneficial by enhancing the yellow and silver eel stocks in a number of water bodies. These included several Danish, German, Swedish and Estonian Lakes, Lough Neagh in Northern Ireland as well as Danish streams and marine areas.

The benefit of stocking can be considered at three geo-political scales:

- local interests (the production gained locally by stocking);
- the national/EMU scale of Eel Management Plans (applying stocking to achieve EMP biomass targets);
- the continent-wide scale (stocking contributing to the general recovery of the stock).

1.2.3 Definition of Net Benefit

For the purposes of this Workshop, and as outlined in the Scientific Justification distributed with the Workshop's Terms of Reference, the definition of ***net benefit*** of stocking is taken as:

"where the stocking results in a higher silver eel escapement biomass than would have occurred if the glass eel seed had not been removed from its natural (donor) habitat in the first place".

There is ample evidence that the release of additional young eels in a water body contributes to the abundance of eel, (production and yield), creating an increased escapement of silver eels from the recipient waterbody – the benefit. From the aspect of the donor habitat, the use of glass eel for stocking can either compete with the demand for other uses (direct consumption, aquaculture), or create an increase in demand, leading to an increased exploitation rate in the donor area. Hence, the use of glass eel for stocking can either be contrasted to other uses (option A Figure 2), or to a reduction in exploitation rate of glass eel in the donor area (option B).

In earlier reports (ICES 2011), option A has been considered, interpreting the net-benefit as the increased production due to stocking, minus the loss of production due to anthropogenic mortality in the recipient area – this approach assumes that the glass eel would have been harvested anyway.

Giving priority to the recovery of the European stock, this led to the recommendation that, the objective of any stocking exercise should be to maximize net benefit to the stock as a whole, i.e. the glass eel be released into areas of lowest anthropogenic mortality.

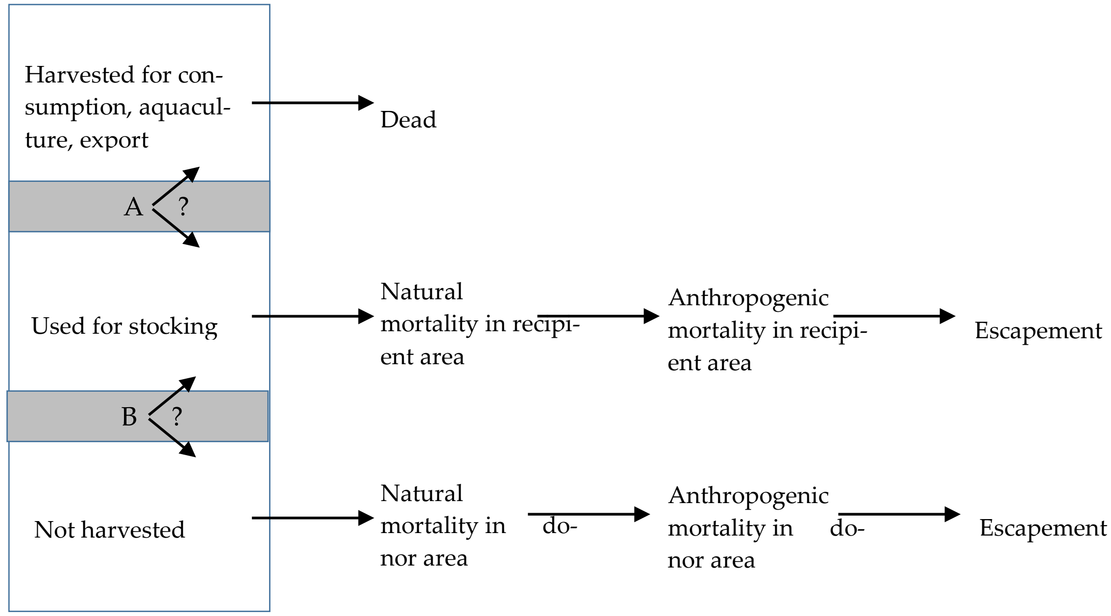

Figure 2. Diagram of the alternative uses of glass eel from the donor area.

Chapter 5 of this report explores option B, using a range of scenarios and interpreting the net-benefit as the increase of production in the recipient area, minus the loss of production in the donor area – (assuming that the demand for stocking has led to an increased exploitation rate in the donor area, or alternatively, that a reduction in the glass eel demand for stocking results in a lower exploitation rate in the donor area). Only marginal effects are analysed since the effects of any ban on stocking or other exploitation are much more unpredictable.

1.3 Stocking and the Eel Recovery Regulation 1100/2007

During the creation of the Eel Regulation in 2007 the Council of the European Union noted that in relation to eel there are diverse conditions and needs throughout the Community which will require different specific solutions or management actions.

To that effect Article 2(8) of the 2007 Eel regulation 1100/2007 stated that:

(8) An Eel Management Plan may contain but is not limited to, the following measures:

- Reducing commercial fishing activity
- Restricting recreational fishing
- **Restocking measures**
- Structural measures to make rivers passable and improve river habitats, together with other environmental measures.
- Transportation of silver eel from inland waters to waters from which they can escape freely to the Sargasso Sea
- Combating predators
- Temporary switching off hydro-electric power turbines
- Measures related to aquaculture

The provision of funding towards the purchase of glass eel for such *restocking me*asures was made available by the EU via grant aid from the European Fisheries Fund (EFF).

In addition to the use of stocking as a management measure Article 7 of the Regulation requires that any Member State that permits fishing for glass eels/elvers (defined as eels < 120 mm total length, used throughout) must reserve at least 35% of the catch for stocking purposes within the EU in the first year of a compulsory EMP (which is assumed to be 2010), increasing by at least 5% per year to achieve at least 60% by 31 July 2013.

Lastly, Article 12 stated that "no later than 1 July 2009, Member States shall take the measures necessary to identify the origin and ensure the traceability of all live eels imported or exported from their territory."

So in essence this report will have been written during a time when:

- EU funding was available towards the purchase of "seed" for stocking
- 60% of all glass eel harvested should have been made available for stocking purposes within the EU for the preceding 3 years,
- The transfer of such glass eel should have been traceable for the preceding 7 years.

1.4 Previous ICES Reviews on Stocking.

ICES (ICES, 2006, 2007, 2008. 2009, 2011, 2013a) has repeatedly reviewed the issues surrounding capture, transfer and stocking of European eel, almost as a standing item on its annual agenda. These reviews were originally commissioned with the 1990s view (Moriarty and Dekker ,1997; Watson *et al.*, 1999; Moriarty 1999) that glass eel could be redistributed from European "donor" estuaries with glass eel fisheries, (such as the UK, France, Spain and Portugal) and used to enhance "recipient" fisheries or stocks where recruitment is low, but within the natural range of eel.

Over the period of these ICES reviews, the tones have changed, with fisheries declining due to continuing decline in glass eel and stocking increasingly seen as a protective or conservation measure. Recent ICES advice (ICES, 2011; 2013) continues the trend toward only advising stocking where there is a high probability of net benefit to the production of silver eels and by inference, the spawning stock.

Concerns about current eel stocking practices have been expressed and its effective contribution to ensure increased silver eel production has been raised. It remains an ICES recommendation that all stocking activity be designed to include traceability of eel into later life stages by using permanent marking of bone structures (ICES, 2009; 2011). Such marking would effectively discriminate between the origins of maturing eels and fall in line with the needs of Article 12 in the Eel recovery Regulation.

The most recent reviews (Pawson, 2012; WGEEL 2011) on the value of stocking state that there are major knowledge gaps to be filled before firm conclusions either way can be drawn. There was almost no new evidence available to Pawson in 2012 that was not considered by ICES in its 2011 report and the conclusions and recommendations of both are similar:

1) Translocated and stocked eel can contribute to yellow and silver eel production in recipient waters, but evidence of their contribution to actual spawning is limited by the general lack of knowledge of the spawning of any eel.

2) In addition to investigations on the value of stocking for the enhancement of silver eel escapement in distinct EMUs, it was recommended that internationally coordinated research is required to judge the net benefit of stocking for the overall population.

3) Assessments of carrying capacity estimates of glass eel donor estuaries are absent.

4) Detailed mortality estimates along glass eel trade channels are required.

5) The impact of holding and maintenance feeding of elvers in aquaculture with regard to a possible adaptation to culture conditions (as known from other fish species like salmon and trout) is unknown.

6) Ongrown eels exhibit no advantage in growth and survival compared to stocking with glass eel: The only benefits conferred wer allowing temperature conditions to become suitable in the recipient waters, and the facilitation of veterinary observations during quarantine.

7) The most frequent shortfall in early life history mortality and development assessments was the absence of controls in the studies.

8) Analyses of the life histories of those glass eels "left behind" at the donor estuaries is a prerequisite to any net benefit assessment and does not feature in any of the studies reviewed.

1.5 ICES Advice in relation to stocking 2015

The most up-to-date stocking advice from ICES (2015) reiterates the main conclusions and recommendations from so many previous reviews:

- ICES notes that stocking of eels is a management action in many eel management plans, and that this stocking is wholly reliant upon a glass eel fishery catch to provide "seed".
- There is evidence that translocated and stocked eel can contribute to yellow and silver eel production in recipient waters, but evidence of contribution to actual spawning is limited by the lack of knowledge of the spawning of any eel.
- Internationally coordinated research is required to determine the net benefit of stocking on the overall population, including carrying capacity estimates of glass eel donor estuaries as well as detailed mortality estimates at each step of the stocking process.
- When stocking to increase silver eel escapement and thus aid stock recovery, an estimation of the prospective net benefit should be made prior to any stocking activity.
- Where eel are translocated and stocked, batch marking to distinguish between groups recovered in later surveys should be undertaken to evaluate their fate and their contribution to silver eel escapement.

It is on the back of these recommendations that this report reviews the latest science in relation to stocking with the objective of updating our knowledge on the net benefit of stocking to eel recovery.

1.6 Introduction to the Workshop WKSTOCKEEL

The ICES Workshop on Eel Stocking (WKSTOCKEEL), chaired by: Derek Evans, UK, met in Toomebridge, N. Ireland, 20–24 June 2016, following the Recommendation from WGEEL 2015 that:

"A workshop is convened to update knowledge on the net benefit of stocking to the recovery of the eel stock, and to make proposals for research to fill any crucial knowledge gaps that prevent a definitive advice on stocking as a stock conservation measure (WKSTOCKEEL)".

Eighteen EU experts attended the meeting, representing 6 countries. One representative of the EU Commission DG MARE attended as a participant. A full list of the meeting participants is provided in Annex 3.

1.7 Terms of Reference

The Workshop was tasked by ICES to consider the following terms of reference (ToR):

e) Review and consider recent research into the net benefit of stocking eel for contributing to the spawning stock, including updating recent reviews (including ICES 2013 & Pawson 2012) and prepare a review paper for a scientific journal if appropriate;

f) Identify knowledge gaps currently preventing a definitive determination of the net benefit of eel stocking (see a), and prioritise these gaps in terms of their impact on the uncertainty of net benefit;

g) Design approaches to address the highest priority knowledge gaps (b), including methods, expertise and situations required, and identify potential funding mechanisms;

h) Draft proposals for funding support to address these highest priority knowledge gaps (c).

The meeting was opened at 14:00 on Monday, 20 June at the headquarters of the Lough Neagh Fishermen's Co-operative Society Ltd (LNFCS). The Workshop was given a welcoming introduction and summary on the historic use of stocking on Lough Neagh by Patrick Close Chief Executiveof the LNFCS and a welcome by Seamus Connor Chief Fisheries Officer Inland Fisheries within the Department of Agriculture, Environment and Rural Affairs (DAERA).

WKSTOCKEEL 20–24 June 2016

1.7.1 Discussion points

The meeting agenda (Annex 4) was discussed and agreed, followed by a preliminary discussion into the ToR (Annex 5) assigned to the workshop.

The Workshop noted that the ToR did not request the provision of a qualitative judgement or advice on the use of stocking, and propose that this should be directed to an appropriate fora such as WGEEL.

Net Benefit was taken as the definition provided under Section 1.2.3

1.8 Designation of work areas

Following a more detailed group discussion of the ToR it was decided that a division into sub groups would be the most suitable strategy to progress the Workshop. Given the interconnected nature of the questions raised by the ToR it was not practical for a specific subgroup to tackle a specific ToR. Groups were assigned topics, which formed the basis for each chapter ranging from updates of findings associated with stocking risks to identifying and prioritising data/knowledge gaps.

The opening day of the meeting concluded after the first round of presentations given in relation to studies directly linked to eel stocking. Presentations resumed on Tuesday morning and summaries of their findings are provided in Annex 6.

2 Origin of glass eel stock

Given that glass eel from the European eel cannot be produced artificially, stocking materials can only be obtained by catching eels in the wild. ICES (2008 & 2011) have repeatedly recommended specific considerations prior to the capture of a decreasing glass eel resource for use in stocking:

- A demonstrable surplus should exist within donor glass eel stocks (i.e. those donor EMUs will still achieve their conservation target having removed a component of their recruitment);
- The mortality of recruits from donor estuaries used in stocking must be taken into account;
- Anthropogenic mortality in the recipient areas is minimized.

There is a belief that:

i) density dependent mortality on glass eel and elvers will be at such levels under conditions of high recruitment that many of the recruits would die of natural mortality causes and therefore;

ii) fishing is only taking eels from that ‘surplus’ and so has little effect on recruitment into the ‘growth stage’ population;

iii) Furthermore, that recruitment overfishing could be counterbalanced by the use of ‘excess’ glass eel in restocking (Moriarty & Dekker, 1997).

However, although (i) is biologically sound, there appears to be little or no scientific evidence to support (i) or (ii) for eels.

Knights *et al.* (2001 EA report) postulated a very high natural mortality between glass eels arriving on the Continental Shelf and the early elver/juvenile stages, but these were based on speculations by Tesch. In the words of Knights *et al.*, “In the absence of firm data, his (Tesch) estimates were based on ….”, and “Tesch’s estimates for eels in the 1970s are very speculative and cannot be validated”.

Knights *et al.* (2001) imply a very high natural mortality in the Severn Estuary in the early 1990s, based on the estimated fishing mortality of <0.5% in 1991 from a mark recapture study and recruitment upstream after the fishery in 1994 of <1% (White & Knights, 1994). However, the recapture rate in 1991 was 0.005% (225 individuals from 45 000 marked) compared with a total catch of 23 million eels, and Knights *et al.*, recognises that the mark-recapture study did not meet many of the assumptions of the analytical method.

Knights *et al.* (2001) concluded that “despite methodological problems and limited evidence, it appears that natural mortality of glass eels is relatively high and exacerbated by density-dependent effects….”. However, we could look at this from the other direction and conclude there is “little evidence”.

Another consideration is the fact that recruitment to the continent is lower now than it was in the 1990s and 1980s when these studies were undertaken (see European eel recruitment indices in ICES, 2017 – WGEEL 2016 report). As a consequence, one could assume that the probability of recruitment high enough to trigger significant density-dependent natural mortality is much lower now than then. However, there is little or no scientific evidence to support this assumption.

2.1 Capture of stocking “seed” and its associated mortalities

The origin of the stocked eels is an important consideration and can have a significant impact on their subsequent survival, growth and ultimately their contribution to escaping silver eel biomass.

ICES recognises that stocking is wholly reliant upon this glass eel harvest to provide such “seed” and that any net benefit from stocking must consider what would have occurred if that seed had not been removed from its natural habitat in the first place. This infers the need for an understanding of natural mortality and life history development at such donor sites against which stocking “associated” mortality and subsequent stocked eel performance can be compared.

Glass eel fisheries are undertaken across the EU (UK, France, Spain and Portugal being the main fisheries) using a wide variety of gears, and fishing methods (ICES, 2012; Briand *et al.*, 2012). Given that regionally the catch has a commercial value alive or fresh dead (and thus influencing the capture methods employed), each combination of country and fishing method provides glass eel of varying quality such as length, weight, pigment stage, and more or less injured.

The mortality incurred by harvested glass eel is not solely limited to the point of capture, but can occur across the range of post-fishing activities that comprise the chain of events involved in stocking such as handling, aquaculture facility retention (extended quarantine), transportation, and actual stocking (Figure 3).

For example, glass eels from the French push net fishery are known to have a high mortality rate compared to hand held dip nets and as such are not considered the best quality for any stocking programme (Briand *et al.*, 2012). However, harvested glass eels grown in captive conditions for lengthy periods prior to stocking will have incurred additional mortalities and appear to develop slow growth rates resulting from their domestication (White and Knights, 1997; Simon and Bramick, 2012; Pederson, 2010).

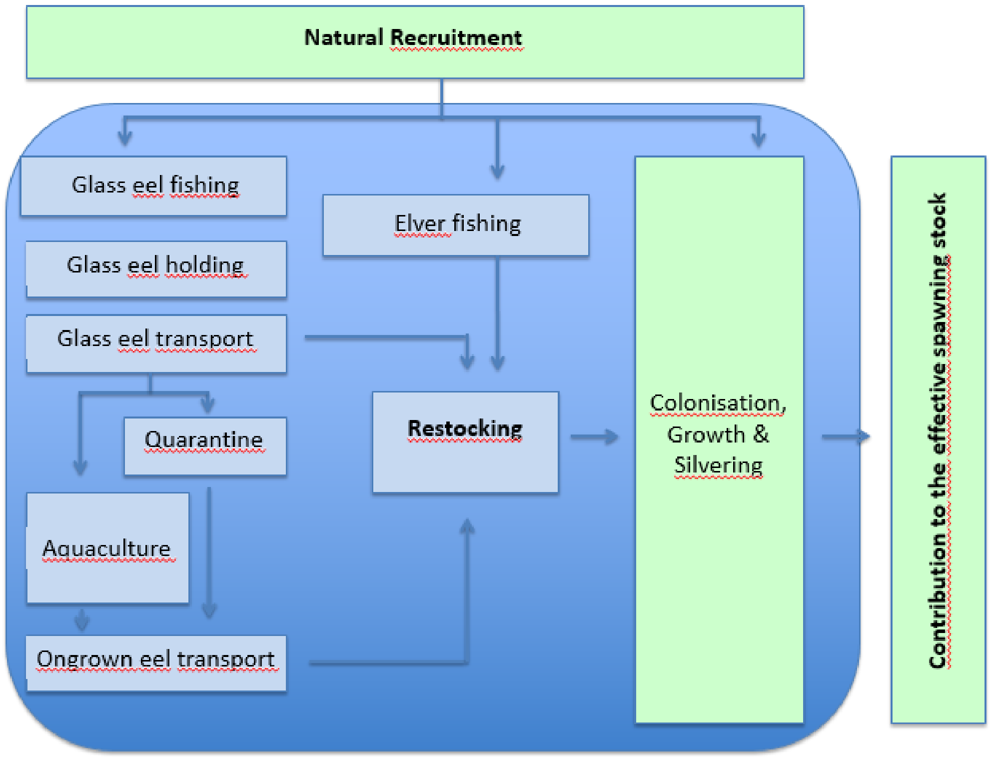

Figure 3. Activities associated with stocking where mortality rates should be considered in comparisons between natural (control) and stocked situations and as such used for net benefit assessments.

2.1.1 Mortalities in push net fisheries

Briand *et al.* (2012), monitored post fishing mortality for two days in catches of glass eel obtained by push net, hand net and trapping ladder fishing methods.

Push net caught eels exhibited post fishing mortalities ranging from 2–82% (mean 42%). Fishing push nets for too long and at too high a speed was shown to cause mucus loss, contributing to death. Follow up treatment of dead glass eel with indigo carmine stain showed that 97% of them had skin injuries.

Leroux and Guigues (2002) produced similar findings at other push net fishing sites giving a mortality rate ranging from 18% to 78% after 36h.

Aside from this direct effect, mid-term or long term effect is not known.

Several recent initiatives by Lopez and Gisbert, (2009) and Pengrech *et al.*, (2015) examined methods aimed at reducing the mortality impacts of glass eel fishing (either on by-catch or glass eel). However neither study was able to remove fishing mortalities in their entirety and considered it an inevitable consequence of the activity.

2.1.2 Mortalities in other fisheries

Briand *et al.* (2012) showed that experimental hand net fishing (used in French, Spanish and UK glass eel fisheries), as well as capturing glass eels in eel ladders, caused very few mortalities.

Crean *et al.* (2012) used an experimental tela net in Ireland (used in Portuguese glass eel fisheries) for glass eel fishing, and an eel ladder for the capture of young yellow eel and found that neither method caused significant, if any, mortalities.

Little is known about mortalities using other fishing gears and whilst the above have only been documented under experimental condition it's likely that given their passive nature large scale (commercial) operations should have a very low mortality.

2.1.3 Use of Aquaculture facilities

2.1.3.1 Holding stocking material

Beaulaton and Briand (2007) consider that natural mortality at the glass eel stage is of the order of magnitude of 0.01 (instantaneous mortality rate per day). In contrast very little data has been published on mortalities during the holding phase of glass eel in commercial scale operations. The only data available come from scientific holding of eels.

Huertas and Cerda (2006) recorded mortality rates ranging from 5% to 47% after 30 days of rearing. Rigaud *et al.* (2015) summarised results from the French stocking program during which batches of glass eels stocked underwent a 15 day mortality test to check their quality. At the end of the period, mortality ranged from a few percent to >40%, driven by the initial quality of the glass eels and the standard of husbandry at the holding facilities.

In the absence of direct studies on commercial holding of glass eel it therefore seems reasonable to assume that during the holding phase between 5 to 30% of glass eel may die depending upon their initial quality and subsequent treatment.

2.1.3.2 Quarantine

An alternative for stocking glass eel directly after catch and transport is to add a holding and quarantine phase for 8 to 10 weeks. The reasons for this are covered in Section 1.4

This method, developed and implemented in Sweden through a centralized holding and rearing facility, is unique in Europe and has helped guarantee a standardized, country-wide mass-marking of stocked eels through SrCl2-staining as advocated by ICES.

Overall mortality starting from loading glass eels at the distributor, including transport mortality to the rearing facility as well as holding and rearing mortalities for the first 70 days is estimated to be around 3% (pers. comm. Fordham).

Mortalities vary considerably with the quality of the incoming glass eel (See 2.1); if the glass eels are of poor quality then the quarantine mortality will also be (sometimes substantially) higher.

In every situation the mortalities follow a similar pattern:

1) Day 1–10: acclimatization/transport mortality

2) Day 10–30: low mortality during the attempted transition to artificial feed

3) Day 30–60: increase in mortality: due to an increase in non-feeders beginning to die

4) Day 60+:mortality slows: as the number of non-feeders lessens

Almost no mortality is documented for the transport from the quarantine facility to the stocking site if the eels are handled correctly and the time from packing to stocking is < 14 hours.

2.1.3.3 On-growing

Glass eels imported to Danish aquaculture facilities and on-grown to a weight of 3 g had a mortality up to 15 % (Pederson, 2010). The glass eels used in these facilities are mostly imported from France though occasionally UK glass eels are used which are noted as having a lower mortality. Further mortality from 3 g to the final product is close to zero. This also means that the larger eels exported from Denmark for stocking (e.g. to Germany at a mean weight of 5–10 g) will also have a mortality of around 15 % whilst on-grown in aquaculture.

2.1.4 Transportation

Transportation and handling of eels before and during stocking may cause mortality if handled without due care. Whilst it is standard practice to reduce mortalities to a minimum by keeping eels moist and cool or in aerated water during transportation (Williams and Aprahamian, 2004), no studies have been carried out to assess the extent of mortality during this activity.

2.1.5 Stocking

Of those Member States actively involved in stocking, adherence to good practice guidelines in terms of minimising additional mortalities (Section 1.2.1) is advocated and put in place. However, little is known about mortalities during actual stocking and no data exist upon which to derive any estimates.

2.1.6 Eel quality

The biometric characteristics of eel used for stocking can show a wide variation ranging from glass eels (UK; Allen *et al*., 2006; Rosell *et al*., 2005) to young eels weighing less than 1g to more than 100g (Denmark, Germany; Dekker, 2015). Obviously eels stocked as glass eel or as 100g eels will not require the same length of time to reach the silver eel stage, and may even show different survival rates/sexual differentiations over this development period (Davey and Jellyman, 2005).

Even glass eels in the same river can show great variation within cohorts between their size and pigment stage, with their average condition varying significantly from one year to the next (Desaunay and Guerault, 1997). Such morphometric variations are likely to generate differences in the performance of these eels when stocked, and thus a need for differential mortality assessments for each variant (Klein Breteler, 1992; Rigaud *et al*., 2015; Geffroy and Bardonnet, 2015).

2.2 Performance of stocked eel

The outcome of stocking has been evaluated by ICES in 2006, 2008, 2009 and 2011 (Section 1.2.2)

Stocking young eel as a means to increase fisheries catches of mainly yellow eel across a range of EU fisheries has proven to be successful in the past (Allen *et al.*, 2006; Moriarty and Dekker, 1997; White and Knights, 1997; Rosell, 2005). Most studies carried out provide evidence that stocked eels survive and grow in comparable ways to natural immigrants (Section 3.4.6.1).

It should be noted that the benefits of stocking with young eels for the production of migrating silver eels will only be realised across a long time frame (5–18 years) given the known differences in silver eel maturation rates across the distribution range of the eel from North Africa to Scandinavia.

However, studies examining early life history post-stocking and linked to the origin of the stocked eels are few and have produced results containing a wide range of mortality and growth rates (Section 4.4).

2.2.1 From glass eel

Klein Breteler (1992) found that the mortality of stocked glass eels from different origin (France, England and The Netherlands) ranged from 10–80% after one year and that higher densities caused higher mortality. In terms of development, he noted a growth of 7 to 17 cm after the first summer and from 18 to 28 cm after two summers in ponds.

Rigaud *et al.* (2015) showed that the mortality of glass eel stocked in France ranged from 85–99% after one year and that this may have been correlated to the initial stocking density, the proportion of natural eel already existing at the stocking site and the quality of glass eel (as given by a 15 days mortality test). Growth of these stocked glass eels ranged from <1cm/year to more than 6cm/year after 1 and 3 years.

2.2.2 From quarantined eel

Stocking quarantined eel is quite recent and restricted to Sweden. Survival rates per year or growth rates to the silver eel stage have yet to be evaluated given the time lags discussed above.

2.2.3 From pregrown eel in aquaculture

Post stocking studies covering the fate of pregrown eel in aquaculture until the silver eel stage are few. Wickström *et al.* (1996) found that aquaculture grown eels of size 3–4 g were recaptured at mean size ca. 420 g with a survival of 11.3 % in a productive lake and 1.7% in a less productive lake. Pedersen and Rasmussen (2015) estimated survival from stocking at 3 g till capture at size 100+ g in a productive brackish Fjord to be 18 %. Eight years after stocking a newly established lake with wild eels of 20 g and cultured eel of 40 g Pedersen, (2000) recorded that survival of the wild eels were minimum 55 % and of the cultured 42 % whilst the mean weight of the wild was 363 g and that of the cultured eel 285 g.

2.3 Performance of natural eel

2.3.1 Natural mortalities

Bevaqua *et al.* (2011) compiled data from publications over the past 30 years on eel mortality during the continental phase of the life cycle for 15 eel stocks. They calibrated a general model for mortality, by considering the effects of body mass, temperature, stock density and gender. Estimated activation energy (E = 1.2 eV) was at the upper extreme reported for metabolic reactions. Estimated mortality rates (ranging between 0.02 year-1 at 8°C, low density and 0.47 year-1 at 18°C, high density for a body mass of 100 g) were appreciably lower than those of most fishes, and attributed to the exceptionally low energy-consuming metabolism of eel.

European eel mortality increases significantly with temperature, consistently with findings at the inter-specific level (e.g. McCoy and Gillooly 2008). Eels inhabiting warm waters are potentially subject to a markedly higher mortality. However, temperature causes both an increase (by direct effect) and a decrease of mortality, (by hastening body growth and reducing the duration of the continental phase, (Vøllestad 1992; Angilletta and Dunham 2003)) so the two effects may at least partially balance each other. The wide geographic distribution of eel species, combined with their panmictic spawning, may preclude them from developing long-term adaptation to local environmental conditions (Aoyama, 2009; Jessop, 2010). Recent investigations on *A. rostrata* question this pattern and suggest divergent natural selection of phenotypes and/or genotype-dependent habitat choice by individuals. This results in renewed genetic differences between habitats occurring every generation in this panmictic species (Pavey *et al.*, 2016).

Mortality is also significantly affected by eel density. At a given temperature, mortality rate of a high-density stock is about three times larger than that of a low-density one. The negative influence of density on adult eel survival has already been shown in local studies (e.g. Vøllestad and Jonsson, 1988; De Leo and Gatto, 1996; Lobon-Cervia and Iglesias, 2008).

2.3.2 Anthropogenic mortalities

ICES (2015) summarises lifetime anthropogenic mortalities (A) as reported by country in the Eel Management Plan Reviews of 2015.

This ranges from low (close to 0) to as high as 4 at the EMU scale.

2.4 Conclusions

- It proved difficult to find any data that was directly linked to commercial stocking operations
- For other aspects (e.g. performance of stocked eel) the published data showed a wide range of results with in many cases no factors listed which may explain these variations.
- Whilst the daily natural mortality at the glass eel stage is considered to be of the order of magnitude of 0.01, there is enormous variation across EU anthropogenic mortalities ranging from close to 0 – 4.

- All of these ranges and uncertainties make it difficult for an accurate (or at best realistic) contribution of a donor mortality estimate into any calculation of net benefit.

3 Risks involved in stocking

3.1 Precautionary principles

ICES has previously advised that a precautionary approach should be applied in assessing risk when the outcome of stocking is uncertain (ICES, 2006, 2007, 2008. 2009, 2011).

Definitions of the precautionary approach as used in relation to fisheries generally start from the standpoint of ***not delaying action*** [to protect stocks] ***where there is uncertainty that the action will succeed.***

For example, "the Rio Declaration":

- In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, **lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures** to prevent environmental degradation.

From the OSPAR convention, specifically relating to fisheries management, this has given rise to:

- "… A lack of full scientific evidence must not postpone action to protect the marine environment. The principle anticipates that delaying action would in the longer term prove more costly to society and nature and would compromise the needs of future generations".

3.2 Precautionary approach and its application to stocking eel

Such interpretations often prove difficult when transposed into discussions surrounding the translocation of eel and often veer to the:

"do not take action (stop stocking) where there are uncertainties over whether or not this will result in viable spawners or further jeopardise the status of the stock..."

However, this raises questions relating to the fundamental role of stocking in the management and conservation of eel. If stocking is required as a key tool to halt the recruitment decline and effect a recovery of the stock, then the precautionary approach indicates:

"that it should take place while applying best practice and minimising all the other risks..."

As such, the lack of any data found in numerous previous reviews on the ultimate fate of either stocked versus natural immigrants throws up a long list of 'what if' scenarios all of which carry with them similar associated risks.

3.3 Major risks

The risks involved in stocking have been discussed at length by ICES, but most notably (ICES, 2011; 2013), with a particular focus on the amount of stocked eel being used throughout Europe and its associated trade (ICES, 2013).

The major risks of concern are:

- Mortality of recruits used in stocking, such as mortality at the initial capture, transport and quarantine stages (Section 2.2.1)
- Movement and stocking of fish may involve a risk of decreased genetic variability or a change in fitness of the stock.

  Traditionally the European eel has been regarded as a single, panmictic stock though this has often been challenged (ICES, 2004,).
- Even in a genetically homogenous population, translocation of eels may disrupt the migration behaviour.

  If there is a phase during the glass-eel stage when cues are imprinted then the spawning migration of relocated eels may be impossible or compromised (Westin 1990). In that case, the effect of stocking will be absent or less than expected resulting in a waste of glass eel.
- The spreading of diseases and parasites is always a biosecurity risk when fish are transported and introduced into new areas.

  In addition to the spreading of eel specific diseases and parasites (e.g. HVA, Evex, and *Anguillicola crassus*), there is a further risk of spreading other fish diseases (e.g. *Gyrodactylus spp.*) and also non-native (potentially invasive) flora and fauna, which can have considerable impact on the local ecology.
- Manipulation of the local eel stock, leading to possible changes in eel growth, survival and manipulation of sex ratios.

  Sex ratio of eels has been observed to vary in relation to stock density in a catchment. The factors involved in sex determination and the optimum sex ratio of the spawning stock biomass (SSB) are unknown, but deliberate manipulation of sex ratio may also be an advantage rather than a risk.

3.4 Examination of relevant new material addressing risks

3.4.1 Fishing and Handling Mortality

Glass eel fisheries are undertaken across the EU (UK, France, Spain and Portugal being the main fisheries) using a wide variety of gears, and fishing methods (ICES, 2012; Briand *et al.*, 2012). In a context of declining recruitment, and historically low glass eel catches, effective glass eel husbandry is increasingly important, and is an essential consideration in gaining maximum value from a limited resource. Associated fishing risks are discussed in Section 2.1.1.

3.4.2 Genetics

3.4.2.1 Structure

Until 2004, no firm conclusions were arrived at with regard to a clear genetic structuring of the European eel. As a consequence the WGAGFM 2004 recommended that the precautionary principle be adopted to protect, as of yet, unresolved or potential genetic variability, recommending the transfer of glass eels between basins should be avoided (ICES WGAGFM, 2004). Subsequently, Dannewitz *et al.* (2005) and Maes and Volkeart (2006) provided comprehensive reviews of the population genetics of the European eel.

Palm *et al.* (2009) again found slight temporal variation between cohorts of adult eels but no geographical differentiation.

Recently, Als *et al.* (2011) published a comprehensive population genetic investigation including for the first time samples of larvae from the spawning area in the Sargasso Sea, along with glass eel samples from continental foraging areas. The results suggest a random arrival of adult eels in the spawning area and subsequent random distribution of larvae across the European and North African coast, providing strong evidence of panmixia in both the Sargasso Sea and across all continental samples of European eel. However, the authors explicitly point to the possibility of within-generation local selection acting on genes in linkage disequilibrium as an explanation of the weak clinal patterns interpreted as genetic structure in previous studies. They recommend further clarification by population genomics analyses aimed at identifying genes under selection in continental and Sargasso Sea samples.

Rapid advancements in sequencing technologies have facilitated new research into the question of panmixia and genetic stock structure in the European eel. Pujolar *et al.* (2014) utilising next generation sequencing and a large SNP data set from eight locations throughout the distributional area observed overall low genetic differentiation (FST = 0.0007) indicating a large degree of gene flow, thus providing further evidence for genomic panmixia in the European eel.

Consequently the practice of stocking eels between catchments and indeed countries within the species natural range appears to present a low risk to genetic integrity. Stocking eels from within the donor catchment or river system would negate some of these potential risks further.

For American eel (*A. rostrata*), the hypothesis of panmixia was also confirmed (Bernatchez *et al.*, 2011).

Even though the eel is looked upon as an almost perfect example of a panmictic species some doubts remain regarding translocation of individuals that already at an early phase maybe selected/adapted for a specific environment. Depending on which characteristics are favoured by this spatially varying selection at the donor site, translocated eels may not perform as expected nor optimally in the receiving environment (Ulrik *et al.*, 2014; Pavey *et al.*, 2015). However, most of this work refers to *A. rostrata*.

Pavey *et al.* (2015) using next generation RAD sequencing found genetic differences between eels inhabiting saline and freshwater habitats. The research suggests that despite panmixia, *A. rostrata* exhibit genetically distinct differences between eels in different eco-habitats. This research has yet to be undertaken for the European eel.

3.4.2.2 Stocking non-native eel

Inadvertent, or deliberate, stocking of non-native eel should be avoided. Growth, condition and development of American eels *Anguilla rostrata* that were introduced into a European river to estimate their competitive potential in a non-native habitat were investigated (Marohn *et al.*, 2014). Results demonstrated that *A. rostrata* can develop normally in European waters and successfully compete with the native European eel. This study indicated that *A. rostrata* can be a potential competitor with the native fauna in European fresh waters reinforcing the need for strict import regulations to prevent additional pressure on *A. anguilla*.

3.4.3 Migration

3.4.3.1 Active migration

Many studies have now been undertaken and provided results that confirm the initiation of successful silver eel migration cues followed by successful attempts at migration.

In 2004 and 2005 Pederson studied silver eels of stocked (N=143) and wild (N = 450) origin which were Carlin-tagged and released in the bottom of the Roskilde fjord. The result was a higher recapture rate of wild compared to stocked eels though the difference was not statistically significant. Independent of eel origin (wild and stocked), both eel types were caught in the same proportion in the southern part of the fjord and in the northern part of the fjord indicating that the stocked eels migrated toward the outlet of the fjord together with the wild silver eels (Pedersen, 2009).

Since 2006, 869 eels of varying size and sexual maturity have been tagged in Estonia, upstream of hydroelectric power plants in Narva. All eels in the area above the power plant were considered to be of restocked origin. A total of 93 eels were recaptured, mostly in the lakes where they were marked however, a few recaptures (7%) taken outside the immediate vicinity of the tagging area were all migrating in a direction towards the outlet of the Baltic Sea (Järvalt *et al.*, 2010).

With respect to silvering, there is evidence that stocked European eels silver and start their descent to sea in a comparable way as natural immigrants. Pedersen (2010) found previously stocked European eel in a Danish brackish water lagoon to start their travel to sea as silver eel alongside natural immigrants. Verreault *et al.* (2010) made a similar observation for *A. rostrata* in St Lawrence tributary, where previously stocked eel where found to silver and descend into the estuary on the same route in a comparable manner to wild eels.

The doubt about the ability of stocked eels to navigate properly during their spawning migration, is based solely on the experiments made by Westin in the 1990s.

Since then, Westerberg *et al.* (2014) undertook a series of tagging experiments using satellite tags, data storage tags and acoustic tags to test the hypothesis that eels translocated 1200 km from the UK to Sweden differed in their ability to migrate compared to naturally recruited eels. Eels were tracked more than 2000 km along a route that, after leaving the Skagerrak, followed the Norwegian Trench to the Norwegian Sea, turned south and west along the Faroe-Shetland channel before emerging into the Atlantic Ocean, and then continued west.

These results provide the first empirical evidence of a Nordic migration route and do not support the hypothesis that a sequential imprinting of the route during immigration is necessary for adequate orientation or behaviour during the adult spawning migration.

For the American eel, it is known that stocked eels are migrating out of the St Lawrence Systems at an earlier age, 4–6 years old, than their wild counterpart, 20–25 years old, (Verreault *et al.*, 2010.), possibly associated with their origin or increased growth rates (Pratt and Threader, 2011). Although the exact numbers of stocked eels leaving the system is still unknown, it may be significantly higher than currently thought because silver eel fishing gears in the St Lawrence River and estuary are not designed to capture these smaller silver eels. What is known is that the stocked eels can at least initiate their spawning migration.

Recent studies (Prigge *et al.* 2013, Sjöberg *et al.* 2016) found that stocked silver eels migrating to the Baltic Sea may have difficulties in finding the outlets of lakes or to migrate as fast as eels of natural origin. However, these works suggested that eels in general had difficulties finding the outlet in complex lakes without guiding currents and an easily recognized outlet.

3.4.3.2 Magnetic Orientation and migration cues

Durif *et al.*, 2013, showed that yellow eel change orientation in response to applied changes in magnetic field suggesting that yellow eel have a magnetic compass, and could use this sense to orient in a learned direction. This has advantages for seaward migration, where displaced silver eels would be able to resume migration in a correct direction. As temperature related shifts in orientation were exhibited, this shows that eels did not orient to an innate course, but is perhaps linked to seasonal changes in behaviour. As such, there is currently no evidence to suggest an "imprint" laid down by an eel in earlier life stages that may be used to inform navigation during the spawning migration. Therefore, it is currently thought that translocation is unlikely to cause disorientation and failure to navigate correctly, a finding supported by Westerbeg (2014).

Despite several investigations using otolith chemistry and other means to quantify the contribution of stocked eels to the spawning run, no firm conclusions can be drawn. A rough estimate based on the stocking figures and subsequent silver eel run in the Baltic came to the conclusion that the observed percentage of silver eels from stocking origin is reasonably in agreement with expectation: there is no reason to believe they all fail, nor to consider stocking a panacea. The parallel development of stocking and escapement also indicates that the fitness of the stocked and naturally recruited eels is similar (Pederson, 2009 & 2010).

3.4.4 Biosecurity risks

3.4.4.1 Spread of diseases and parasites

Parasites that have caused serious problems in culture among captive European eels include *Pseudodactylogyrus anguillae* (Buchmann 1988), *Ergasilus sieboldi* and other *Ergasilus* spp. (Tuuha *et al.*, 1992). While the impact of parasites, particularly the infection with and spread of, the swimbladder nematode *Anguillicola crassus* has been investigated in greater detail (Lefebvre *et al.*, 2013), eel viruses have received less attention. Various viruses have been isolated from European eel, including the rhabdoviruses eel virus America and eel virus Euopean-X (EVEX), the birnavirus infectious pancreatic necrosis virus as well as a herpesvirus, *Herpesvirus anguillae* (HVA) (Sano *et al.*, 1977; Jørgensen *et al.*, 1994; Davids *et al.*, 1999; van Nieuwstadt *et al.*, 2001; van Ginneken *et al.*, 2004; van Ginneken *et al.*, 2005). Among these, EVEX and HVA have received most attention. While some authors (Davids *et al.*, 1999; Lehmann *et al.*, 2005) consider HVA as the most significant viral threat due to documented losses in aquaculture as well as in the wild under certain environmental conditions (Scheinert and Baath, 2004), proven negative impacts caused by EVEX are rare and basically restricted to one publication by van Ginneken *et al.* (2005), showing that European eels infected with EVEX-virus suffered from haematocrit decrease related to distance during simulated migration in large swim tunnels, developed haemorrhage, anaemia and died after 1000–1500 km migration.

Recent investigations on HVA and EVEX infections of glass eels retained for stocking programmes showed the presence of both viruses at yet unknown, but obviously source-dependent infection rates (Bandin *et al.*, 2014). Deliberate infection with HVA is reported as a practice to avoid uncontrolled disease outbreaks in aquaculture (EFSA 2008), and includes the ongrowing of glass eel for subsequent stocking. However, whilst the impacts of the anthropogenic spread of viral diseases via stocking for the wild stock are unknown potential vector routes and risks should continue to be assessed and avoid. Long term stocking programmes in the UK and Sweden have demonstrated that the application of good practice guidelines can negate biosecurity concerns (Rosell *et al.*, 2005; Wickstrom, 2012).

3.4.4.2 Introduction of non-native species

Other species can be inadvertently introduced with any stocking of live fish. A significant risk exists to the integrity of the local aquatic ecology due to the introduction of non-native (potentially) invasive species during the stocking procedure. The transport medium (e.g. water, ice, eel slime) can also be a source on non-native species and / or pathogens.

There are many examples of introduction causing changes in the ecological balance of a waterbody such as the now widespread occurrence of zebra mussel. A new example is the potential for the introduction and spread of the 'killer shrimp'. The Ponto-Caspian amphipod *Dikerogammarus villosus* was first recorded in the UK by MacNeil *et al.* (2010). Its relative *D. haemobaphes* was subsequently recorded in the river Severn catchment in 2012. This species is considered highly invasive and is known to exhibit predatory behaviour towards a range of macroinvertebrate taxa and fish (Dick *et al.*, 2002).

3.4.5 Eel Quality

Spawner quality, in terms of health status and fitness of mature eels, is considered one of the key elements for successful migration and reproduction (ICES, 2008; 2010; 2016).

Besides the actual ability of eels to reach their spawning grounds calculated on the basis of energy storage in their lipid reserves alone (Clevestam, 2011), quality of spawners, (as a function of parasitism, diseases, contamination levels and biomarker responses) may decrease their condition and overall chance of successful reproduction (Geeraerts & Belpaire, 2010). Several publications have shown that habitats of the continental growth phase are important for the composition and amount of incorporated contaminants

(Belpaire, 2007, 2008; Geeraerts & Belpaire 2010; Sühring 2013, 2014; Arai & Takeda 2012; Freese, 2016) with eels in some regions exhibiting high levels of contaminants way above the threshold for human consumption while other regions have relatively low levels of contaminants. Many eels in some of these habitats will, as silver eels, exceed the minimum risk levels (MRLs) for human consumption (EC Regulation No 1881/2006) as well as those levels thought to impair normal embryonic development of eels (Palstra *et al.*, 2006).

A number of different chemical contaminants have been described in the literature which have been shown to negatively affect overall health and fitness of fish (Belpaire, 2007, 2008; Geeraerts & Belpaire 2010; Sühring 2013, 2014; Arai & Takeda 2012; Freese 2016). Dioxin-like Polychlorinated Biphenyls (dl-PCBs) for example, are among the best known persistent organic pollutants potentially affecting the reproductive capability and health status of eels. With this in mind, it must be considered that eels stocked into and subsequently growing up in less polluted habitats are more likely to produce healthy offspring than those from highly polluted habitats.

While we are able to estimate silver eel escapement from the majority of EMUs, there is currently no known way to evaluate or quantify their effective reproductive capacity. Therefore it is currently not possible to undertake a full generation evaluation of this spawning stock be they derived from naturally recruited or stocked glass eels.

3.4.6 Growth and development of stocked eels

3.4.6.1 Contribution to recipient habitats

Stocking young eel as a means to increase fisheries catches of mainly yellow eel across a range of EU fisheries has proven to be successful in the past (Allen *et al.*, 2006; Moriarty and Dekker, 1997; White and Knights, 1997; Rosell, 2005). Likewise Psuty and Bohdan (2008) confirmed similar findings in the Vistula Lagoon of the Baltic Sea whilst a Swedish review (Pawson, 2012) concluded, that most of the studies carried out provide evidence that stocked eels survive and grow in comparable ways to natural immigrants. The choice of stocking material seems not to influence growth. Recent Lithuanian studies (Lin *et al.*, 2007) did not find growth differences between naturally recruited and stocked European eel in freshwater lakes and brackish lagoons in Lithuania. For American eel, Verreault *et al.* (2010) revealed a faster growth of stocked eel compared to naturally migrating counterparts in the St Lawrence river.

Concerning possible site-specific effects, Cote *et al.* (2009) observed significant growth differences in *A. rostrata* glass eel of two different origins which had been reared under similar conditions in salt and freshwater aquaria for 70 days. At the same time, glass eel of both origins grew faster in salt water than in freshwater. This also applies to *A. anguilla* as shown for different life stages by a number of studies (e.g. Melia *et al.*, 2006; Edeline *et al.*, 2005).

Contrary to most studies showing an equal growth of stocked eel and natural recruits, Tzeng examined the performance of stocked vs. natural eels in the Baltic Sea, namely from Latvia (Tzeng *et al.*, 2009) indicating a slower growth of stocked eels. In this study they categorized sampled eels from three inland waterbodies into stocked and naturally recruited from the life-history trajectories found when analysing strontium-calcium ratios in the otoliths. Their results indicate a slower growth rate in stocked eels from two of the three habitats studied. However, they suggest that the differences found between wild and stocked eels might be influenced by the productivity where the eels were grown most of their lives which may not be reflected by the site of catch.

Simon and Dörner (2013) reported that European eels stocked as wild-sourced glass eels showed a better overall performance of growth and survival compared with farm-sourced eels after stocking in five isolated lakes within a seven-year study period in Germany. Eels stocked from farm origin lost their initial size advantage over eels stocked as glass eels within 3–5 years after stocking. This study coupled with results of previous studies (Simon *et al.*, 2013) suggests that stocking of farm eels exhibit no advantage in growth and survival compared with stocking of glass eels if stocking occurs at an optimal time in spring. These echo similar findings as reviewed by Pawson (2012) and ICES (2011) (Section 1.4). In addition, the use of relatively expensive farm eels may provide no general advantage over stocking of glass eels presumably because they need a longer period to switch from artificial food to natural prey and to adapt to new foraging strategies.

In southern France, Desprez *et al.* (2013) estimated demographic parameters of a stocked population (stocked as yellow and glass eel stages) in a 32-ha freshwater pond in the river Rhône delta using a multistate capture–recapture model. They estimated population size and predicted the number of future spawners obtained by stocking. They found that the stage in which eels were stocked did not influence their future survival and that the maximal number of silver eels was quickly reached, after three years following stocking. They concluded that stocking experiments in the Mediterranean region are efficient for fast production of silver eels.

According to a long-term study by Pedersen (2000), stocked eel survival is lower than wild eel survival. Cultured eels were marked using visible implant tag and stocked alongside wild untagged eels. Recapture rate by trap and fyke netting was used in order to monitor survival and growth after seven years. Pederson found a higher survival rate (55–75%) in the wild eel component compared to the stocked (42–57%) with a higher biomass of wild eels than stocked.

Pedersen (2009) looked at the disappearance rates in eels (3 and 9 g) stocked in some Danish lowland streams. He used electrofishing to measure the daily disappearance, i.e. emigration was included in the estimates of natural mortality. The daily instantaneous mortalities in the short term as well as long term were very high, 0.006–0.153 corresponding to 2.19–55.84 on a yearly basis. He also referred to earlier work completed in Denmark. Here, smaller eels (0,3–1.1 g) were used (Berg & Jörgensen (1994)). This was a short term study and 66–92 % of the stocked eels were gone after 100 days. Both studies noted that emigration (and not solely mortality) may be a major component of losses from the system.

Except for length and weight gain, comparisons concerning other growth and fitness parameters between stocked and naturally recruited eel are rare. Tzeng *et al.* (2009) investigated the habitat preferences and recapture rates between wild and cultured Japanese eels stocked in a coastal lagoon. There were no obvious differences between eel of the two origins and both stayed mainly in freshwater.

3.4.6.2 Sex differentiation and maturation

Sex differentiation in eel remains poorly understood but is not likely to take place before the fully pigmented young eel stage and at a body length of <15 cm (Geffroy and Bardonnet, 2016).

Genetic and environmental factors have been implicated in sex determination and differentiation in eel resulting in sex ratios which can vary greatly both temporally and spatially across eel stocks, (Parsons *et al.*, 1977; Rosell *et al.*, 2005). There is some evidence that the proportion of females in migrating silver eel may be increasing over the last decades (Poole *et al.*, 1990; pers. comm. Belpaire) and that male percentage is higher in the lowest part of catchments (i.e. estuaries and lagoons) (Ibbotson *et al.*, 2002). Understanding the relative contribution of both genetic and environmental factors is fundamental to addressing ongoing efforts to explain the reasons why male and female eels undertake different life history strategies and why the sex ratios of adults in eel populations are often highly skewed. It is also important when developing models to predict consequences of management actions (such as stocking) on spawning–stock biomass and abundance.

Pedersen (2010) reported after stocking of elvers into a brackish water lagoon a sex ratio of 1:2 (M:F) in catches of those eels in the yellow stage though no information on the sex ratios of natural immigrants in this waterbody was available for comparison.

For the American eel, (Pratt and Threader, 2011) assessed gender for 13 sexually differentiated eel in the St Lawrence river previously stocked as glass eels and found five of them being males. This is noteworthy because previously only females had been detected in this watershed. The authors assume this is due to either the long holding time of glass eel of several months before stocking and/or density effects in the recipient area.

The main impediment to address these questions is related to the difficulty of differentiating between male and female during early stages of life history. The development of sex-associated markers would bypass this problem and, hence, facilitate the understanding of the sex determination mechanism in eels. New advances in sequencing methodologies (i.e. Next Generation Sequencing) now allow for this task to be undertaken.

3.4.7 Use of Aquaculture

Frequently there is a noted decoupling in the timing between the arrival of glass eel stock at donor estuaries and temperature suitability at the recipient location for the stocking, particularly in N. Europe (ice bound) (ICES, 2013). To circumvent this issue, glass eel can be held in culture facilities and ongrown for a period of weeks or months until suitable conditions are available for their introduction into the wild. This practice carries with it additional risks.

Holding glass eels with at least maintenance feeding, until the time that they can be stocked with a better chance of survival in otherwise cold or ice-bound northern waters is a beneficial option, although there do not appear to be any benefits (in terms of overall survival and growth) arising from on growing of glass eels in aquaculture facilities before stocking (Section 1.4), However, there are associated risks attached to stocking glass eel, young yellow eel and on-grown eel from aquaculture. These risks were originally identified by WGEEL (ICES, 2008) and include deliberate/accidental spread of parasites, diseases, altering sex ratios, genetic and biological fitness as discussed above.

Precautions must also be taken to ensure that the genetic integrity of the European eel is not compromised by stocking with aquaculture-grown eels that may contain *A. rostrata* (Marohn *et al.*, 2014) or eels discarded by the aquaculture industry due to poor growth rates or condition.

3.5 Conclusions

- Capture & Handling Mortality: some glass eel fisheries and their associated gears impart significant mortality and post-capture stress while other gear types and methods are relatively benign.
- Genetics: The European and North American Eel stocks are both considered strongly panmictic. Stocking eels between catchments and countries within the species natural range appears to present a low risk to genetic integrity.
- Migration: There is strong evidence that silver eels derived from stocking, mature, migrate and navigate in a similar fashion to native origin eel.
- Biosecurity: The spread of non-native invasive species, including parasites and pathogens, poses an additional threat to the ecology of the recipient catchments but can be avoided or reduced by the application of robust biosecurity protocols currently in use as demonstrated by long term stocking programmes in the UK and Sweden.
- Eel Quality: Stocking should avoid areas known to impact on the quality of eel through contaminants, and/or pathogens. Low Eel quality is likely to impair migration, spawning success and the viability of offspring. Differences in eel quality has not been quantified for silver eel derived from either native or stocked glass eels.
- Growth & Survival: Stocking young eel is known to increase yellow eel stocks. Ongrown eels exhibit no advantage in growth and survival compared to stocking with glass eel whilst stage stocked is not likely to influence their future survival and silvering rate.

  Differences in growth vary although most studies indicate little difference between stocked and wild origin
- Sex Differentiation: This appears to be hugely variable and easy to manipulate. Stocking is likely to increase the proportion of males, by altering (increasing) overall eel density.
- Aquaculture: The only benefits conferred were allowing temperature conditions to become suitable in the recipient waters prior to stocking and veterinary screening during quarantine.

4 Monitoring methods for the evaluation of stocking and associated knowledge gaps

4.1 Introduction

Given that any understanding of the net benefit of stocking is reliant upon monitoring the life history of those glass eel not removed from the donor habitat whilst simultaneously assessing the contribution of their stocked cohort to the spawning silver eel stock, the intention of this chapter is to:

- describe the current monitoring methods employed to compare the performance (contribution) of eels in a mixed population of both natural and stocked eels;
- identify the most crucial knowledge gaps.

4.2 The need for monitoring

Monitoring is of key importance when trying to investigate highly mobile and long lived animals such as migratory fish species. For eel, many questions remain poorly understood as a consequence of insufficient monitoring, such as the impact of stocking on the survival of various life stages at both the donor and the recipient waterbody (Section 2.2), However, the development and implementation of robust monitoring programmes has lead to an understanding of the migration patterns of silver eels emanating from previously stocked eel (Westerburg, 2014); (Section 3.4.3). As such, monitoring methods are the only way to assess the efficiency and contribution of a management action based around stocking.

4.2.1 Correct description of donor life stage

A significant issue regarding the evaluation of stocking programmes is the lack of consistency when describing the life stage of eels being stocked.

Glass eel stocking has been used to describe

a) completely transparent;

b) slightly pigmented or

c) early elvers

Similarly, eels of farmed origin may have been:

a) quarantined and weaned for 8 weeks,

b) young juveniles reared on commercial pellets for 3–4 months or

c) held in the culture station until they are yellow eels.

In other cases stocking is done using much larger individuals, from 25 to 28 cm TL (Pedersen, 2000), whilst Leopold and Bninska (1984) performed stocking programmes without any consideration of size or stage.

Definition of these life stages used is often ambiguous and with this their life history prior to stocking. As discussed previously (Section 2.1.6) this has implications for assessing survival and growth in each stocking situation, any subsequent stock benefit analyses derived from these assessments and brings with it the need for a range of monitoring methodologies.

4.2.2 Monitoring methods

In order to assess survival of stocked eel between life stages, it is necessary to capture eel from a range of habitats and ages. A detailed guide to using some of these methods is available in the Environment agency handbook, "Monitoring elver and eel populations." (EA, 2008).

	Glass eel/elver	Yellow	Silver
Estuary	Towed Icthyoplankton net	Fyke	Fyke
	Trapping ladder		
	Hand net		
	Skirt trap		
Small river	Trapping ladder	Fyke	Fyke
	Hand net	Electrofishing	Coghill/wing net
	Skirt trap		Didson counter
	Electrofishing		Resistivity counter
Large river	Towed Icthyoplankton net	Fyke	Fyke
	Trapping ladder	Electrofishing	Coghill/wing net
	Hand net		Didson counter
	Skirt trap		Resistivity counter
Lake		Fyke	Fyke
	C.. Dolan PhD	Draft netting	
	Lough Neagh	Electrofishing	
		Dorow Trap	

Table 1. The range of Eel capture methods used, as designated by life stage and habitat.

Currently employed sampling methodologies used for monitoring eel populations based on type and habitat are given in Table 1. Novel capture techniques are being designed on Lough Neagh with an emphasis on the capture of small elvers and juvenile eels (C Dolan, ICES 2014), to track early life history of strontium chloride marked glass eel stocked in 2014.

4.2.3 Identification of stocked eel

ICES have consistently recommended that where eel are translocated and stocked, measures should be taken to evaluate their survival rate and contribution to silver eel escapement (Section 1.5). This requires international coordination undertaking batch marking of eel to distinguish groups recovered in later surveys (e.g. recent Swedish, French, and UK marking programmes).

4.2.3.1 Marking eels

When choosing a marking method, one must consider cost, as well as the method's suitability (size, retention) for the life stage to be monitored. Some marking methods are suitable for mass marking of juveniles and are relatively low cost (i.e. chemical marking), whereas physical marking techniques are more labour intensive, with higher costs. Generally mass marking techniques require lethal monitoring

4.2.3.2 Chemical marking

The best means of ensuring conclusive traceability is by using batch or other permanent chemical marking methods targeting bony structures within the eel (ICES 2009; 2011; Wickstrom, 2012). Chemical marking is almost exclusively confined to young (glass eel, elver) stages. The antibiotic OxyTetraCyclin (OTC), the chemical stain alizarin red and the salt strontium chloride have all been used successfully on glass eel (Figure 4). The chemical methods Alizarin red Strontiumchloride (SrCl2) and Bariumchloride (BaCl2) are all considered ideal, both in terms of the mark produced and the procedures' associated mortality rates (ICES 2011; Working group meeting in Germany, 2015). The use of Oxytetracyclin (OTC) is less common and no longer recommended given its antibiotic nature.

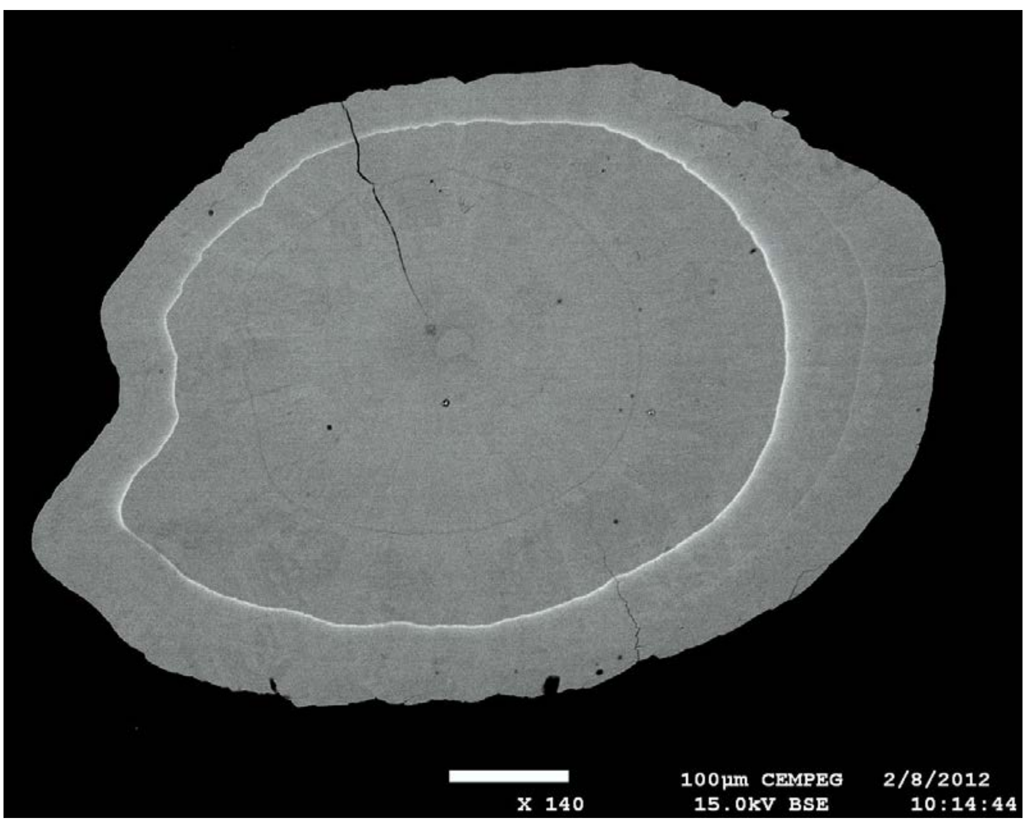

Figure 4. Eel otolith marked with a Strontium Chloride ring (from Wickstrom 2012).

The costs of a mass marking should not only include the actual marking but also the costs of the follow up analyses involved with detecting the mark. Each mass marking process should contain a control group that are held back to check the marking success, and this will inevitably incur additional procedure costs.

Operational costs for the different marking solutions vary by the method used whilst the subsequent detection of the marks produced vary by hardware - Alizarin red needing fluorescence microscopy; that of SrCl2 & BaCl2) needing electron microscopy.

4.2.3.3 Physical tags

Among the internal tags used in eel, coded wire tags (CWT) and passive integrated transponders (PIT) (of different sizes) are commonly used as they also enable individual identification of the smaller eel life stages. Other tags are available for larger stages and include external tags such as Carlin and Floy (Figure 5) which are mainly used for short term mark-recapture studies on migrating silver eels (Rosell *et al.*, 2005). Staining and tattooing using different colours alone or in combinations can also be used in yellow eels of different sizes (Wickstrom *et al.*, 1996). Visible implants (VI) and visible elastomer implants VIE) may also be used. Most physical marking techniques are more effective on larger juvenile eels (10g +) although Pederson has successfully marked 3–5g eels with CWT tags with a high retention rate (Pederson, 2005; 2010).

Figure 5. Silver eel individual identification using numbered Floy tag (Evans).

4.3 Development of novel origin identification methods

Among the novel methods being developed are attempts to assign different otolith zero band chemical signatures (or "fingerprints") to eel from different donor systems (Evans *et al.*, 2014). The principle tested so far is that a glass eel otolith has a specific "fingerprint" derived from a unique combination of different elements in the structure of its zero band matrix, identified using Lazer ablation ICPMS (Sturrock *et al.*, 2015). This elemental composition is directly linked to that of the estuary where the glass eel are caught and is likely driven by local geology, water chemistry and/or industrial activity (Campana *et al.*, 2000). Once embedded into the zero band this elemental composition will remain stored in the otolith as additional annuli are laid down with each years growth. As such the otoliths removed from a silver eel should have retained this “fingerprint” in the zero band and can be used to discriminate on that eel’s origin based on similar analysis of glass eel otoliths. This technique can be rapidly applied and is not reliant upon the growth of chemically marked glass eel; in theory it could have a real time application and be used on all life stages. So far it has been used to successfully identify glass eels from 2 different UK sources (Evans *et al.*, 2014) and it is hoped to expand the study further following this workshop.

Similar analyses examining the chemical composition or unique combinations of fatty acids and/or stable isotopes in eel flesh have been found to be representative of the environment from which they have grown (Bodles, 2016). Bodles suggested that these results could be expanded and used to discriminate between eel stocks though noted that methods of this kind required detailed knowledge of the chemical composition of the potential donor sites and prey items.

4.4 Monitoring different outcomes between wild and stocked eel

Quantitative assessment of the net mortality and survival in the continental stage has been deemed a necessity (WGEEL, 2013). Calculation of mortality and survival, particularly for young life stages, have been assumed from empirical knowledge. For instance, the natural mortality used in the back-calculation of larger eels into glass eel equivalents applies to eels in natural habitats yet the French EDA model includes an additional 20% survival from the glass eel to the yellow eel stage (ICES, 2013). According to French expertise (ICES, 2015), early life stage survival post-stocking depends on numerous factors related to the environment and to the stocking itself as discussed previously (Section 3.4.6.1).

There have been some encouraging reports of contributions of stocked eels to fisheries which have reported survival rates for elvers ranging from 3.5 to 20% (Shiao *et al.*, 2006; Pedersen, 1998; Andersson and Sanstrom, 1992) and a survival rate of up to 80% for yellow eels (McCarthy *et al.*, 1996).

In short, there have been a significant number of studies examining the outcomes of stocking (Section 3.4.6.1) and these have provided ample evidence that translocated and stocked eel contribute to yellow and silver eel production in recipient waters.

As noted so frequently in this report the lack of any controls used in these studies or a simultaneous assessment of the life history of those glass eel “left behind” at the donor site means that, while a local benefit may be apparent, an assessment of net benefit to the wider eel stock is unquantifiable.

4.4.1 Current research on wild and stocked eel outcomes

In order to fill this knowledge gap, a study is currently underway on the Oir river, France, to experimentally evaluate and compare survival rates of glass eels from natural and stocked origin during their first few months. The Workshop notes that this is the only known project of its kind and directly addresses the shortfalls noted above and the recommendations from ICES WGEEL (ICES, 2006, 2007, 2008. 2009, 2011, 2013a); (Section 1.4). The project aims to compare the stocking protocol used in Europe and to set up an experiment to study the early stage (3 month) survival of both natural and stocked glass eel from the same donor habitat (Annex 6, presentation 8).

4.5 Contribution of stocked eel to spawning

In addition to the larger tagging methods described above, several other methods have been designed aimed at tracking larger eel movements in detail, irrespective of being from a stocked or natural origin. Such methods include the use of acoustic tags, radio tags and different kinds of data storage tags (DST). None of these are suitable for small eels as the tags are quite large but they have been used successfully to document the migration of silver eels (from both stocked and wild origin) out of the Baltic (Westerberg *et al.*, 2014; Section 3.4.3.1), and to track the oceanic migration and behaviour of silver eels in the North Atlantic (EELIAD project 2013 Wahlberg *et al.*, 2014).

However, none of these studies were able to document the successful migration to the breeding grounds and subsequent spawning of any of the silver eels tagged, let alone discriminate between any differences in these behaviours as a consequence of their origin (from a stocked or wild juvenile eel).

Ultimately the success of a stocking programme will be judged on the ability of resultant silver eels to contribute to future generations.

As found in many previous stocking reviews this contribution is still not quantifiable and is limited by the lack of knowledge on the spawning of any eel.

4.6 Conclusions

- There have been a significant number of studies examining the outcomes of stocking and as found previously they provide further evidence that translocated and stocked eel contribute to yellow and silver eel production in recipient waters.
- However as noted previously the studies lack controls and/or a simultaneous assessment of the life history of those glass eel "left behind" at the donor site. This in effect means that, whilst a local benefit may be apparent, an assessment of net benefit to the wider eel stock is unquantifiable.
- Ultimately the success of a stocking programme will be judged on the ability of resultant silver eels to contribute to future generations. Whilst concerns over migratory pathways have been reduced the contribution of stocking derived silver eel is still not quantifiable and is limited by the lack of knowledge on the spawning of any eel.

5 Knowledge gaps

5.1 Monitoring the contribution and any difference in outcome between wild eel, stocked eel, and those eel left *in situ*

There have been some encouraging reports of contributions of stocked eels to fisheries which have reported survival rates for elvers ranging from 3.5 to 20% (Shiao *et al.*, 2006; Pedersen, 1998; Anderson *et al.*, 1992) and a survival rate of up to 80% for yellow eels (McCarthy *et al.*, 1996). Such translocated and stocked eel are known to contribute to yellow and silver eel production in recipient waters (see also Sections 3.4.6.1 & 4.4).

However, the lack of any controls used in these studies or a simultaneous assessment of the life history of those glass eel left *in situ* are significant knowledge gaps.

5.2 Contribution of stocked eel to spawning

Tracking studies have been used successfully to document the migration of silver eels (from both stocked and wild origin) out of the Baltic (Westerberg, 2014; Section 3.4.3.1), and to track the oceanic migration and behaviour of silver eels in the North Atlantic (EELIAD project 2013 Wahlberg *et al.*, 2014).

None of these studies were able to document the successful migration to the breeding grounds and subsequent spawning of any of the silver eels tagged, let alone discriminate between any differences in these behaviours as a consequence of their origin (from a stocked or wild juvenile eel).

The contribution to spawning of silver eel, derived from stocked eel, is still not quantifiable and is limited by the lack of knowledge on the spawning of ***any*** eel.

5.3 Assessment of stocking scenarios

5.3.1 Choice of case studies

The eel stock is distributed over a myriad of habitats across its range with local characteristics (habitat, biological parameters) varying over very short ranges. Only a small number of these local situations has been analysed, and results are often hard to compare between habitats and/or cases. Hence we selected a few scenarios based on well-documented case studies. In selecting these case studies, the aim was not to provide a representative cross-section of all habitats, but to provide an adequate overview of the range of potential circumstances available. Since the selection of case studies represents only a very small fraction of the (managed) distribution area, all case studies have been anonymised.

In selecting case studies, the following characteristics have been considered:

- **Density of eel in the source area**: Traditionally, young eel have been translocated from areas of high as well as from areas of low abundance. The translocation from high abundance areas transported the young eel to rivers of low abundance, often in different parts of the European continent. This was known as restocking. The transport of young eels from areas of low abundance upstream within the same river basin, to assist them in their migration over manmade barriers, was known as elver trapping or assisted migration. For the areas of high abundance, it has generally been assumed that carrying capacity was limiting the survival in the source area, i.e. the glass eel would have incurred high density-dependent mortality if not captured (e.g. Knights and White, 1998; Moriarty, 1996), but no evidence has been presented.

- **The transport over migration barriers**: In areas of low abundance historically aimed to bring young eels from the unexploited river mouths into exploitable waters upstream. In the current situation of low overall stock abundance, the main aim of this assisted migration is to make habitat available to the eel, and to maintain a natural eel population in those habitats. It is not known what mortality the young eel would incur, if not assisted upstream - but given the currently historically low abundance of the stock, it is not likely to be substantial.
  In the absence of evidence on the level of (natural) mortality in the donor areas and the potential relation to stock abundance, we have assumed that life-time natural mortality is constant across the range, and independent of abundance. Whilst naive, this was the only practical approach available to calculate this assessment.
- **Mortality associated with the capture and handling of eel**: It's likely this mortality varies with many factors, even from day to day in the same fishery. Here we focus on published estimates of handling mortality rates, as associated with different fishing gears, the manner in which these gears are fished, the length of time that the eel are held prior to release, the manner in which they are held, and the distance/length of time/transport method associated with transporting them from holding facilities to the release location.
- **The life stage (size) when stocked**: This varies from identical stage occurring during assisted migration where the eel are caught below a barrier, transported a short distance upstream and released back into the same river basin within a few minutes or hours, to the other extreme where the eel are reared in aquaculture facilities for weeks or months (Section 2.1.3.1).
- **The anthropogenic mortality experienced by the eel in both the donor and the recipient area:** This can include both fishing and non-fishing mortalities. Case studies were selected to cover the range of mortalities actually observed, but no distinction was made between cases with different types of mortality.
- **The natural mortality experienced in the recipient area:** Comparable to the situation in the donor area, the value of this rate mainly depends on intra- and interspecific competition, and is therefore density dependent. Well-based values are currently not available, and we decided to use a constant value for all destination areas.

Based on these characteristics, a number of case studies were selected – for both donors and recipients. These cases were selected on the basis of the availability of information (estimates of mortalities), and the coverage of the full width of the spectrum of cases in the field. It should be noted that this selection is made for illustration purposes only.

For the donor areas, our selection comprised:

1) an area using hand-held nets with a low handling mortality;

2) an area using fast-operating stow-nets creating a high handling mortality;

3) an area using slow-operating stow-nets with an intermediate handling mortality;

4) an area using stow-nets, from which the glass eel is used directly for stocking, or alternatively is on-grown in aquaculture before being released;

5) a low-density area catching young recruits, assisting their migration over the barriers within the same river.

For the recipient areas, this comprised:

1) an exploited lake, with hydropower stations downstream;

2) an exploited lake;

3) an exploited system of lakes and rivers;

4) an unexploited river;

5) unexploited lakes/lagoons;

6) other, land-based usage of the glass eel (i.e. no release).

5.3.2 Scenario evaluation procedure

In catching and trans-locating young eel from one area to another, one might create a net increase in the quantity of silver eels escaping from the continental stock, or a net decrease – depending on whether the benefits (in terms of silver eel biomass gained) exceed the costs (biomass lost), or not. By exploiting glass eel in the donor area, silver eel production and escapement is reduced by the quantity of glass eel harvested, and depreciated by the mortality in-between the glass eel and the silver eel stage i.e. life-time natural mortality, and life-time anthropogenic mortality. By releasing glass eel in the recipient area, silver eel escapement is augmented by the same quantity of eels, depreciated by the handling mortality during catch and transport, as well as the total mortality until the silver eel escapement i.e. life-time natural mortality, and life-time anthropogenic mortality.

In Table 2, the net result is expressed as the logarithm of the ratio of benefits to losses, i.e. $ln\left({}^{gain}/_{loss}\right)$, which is positive for a net gain, and negative for a net loss. This indicator of net-benefit is independent of the quantity of eel considered; the calculation in Table 2 is actually made on the basis of (lifetime) mortality rates - as reported in the 2015 stock status reports (ICES 2016) – as

$$ln\left({}^{gain}/_{loss}\right) = \left(\sum M_{source} + \sum A_{source}\right) - \left(\sum M_{destination} + \sum A_{destination} + Handling\right)$$

where M=natural mortality, A=anthropogenic mortality, Handling=handling mortality, and all sums are taken over the full (continental) lifetime.

This indicator of net-benefit depends on estimates of lifetime natural mortality, both in the donor and the recipient areas. As discussed previously in this report the number of studies assessing natural mortality is extremely limited. Most often, a value of M=0.1385 per annum is used, referring to Dekker (2000) as the source. Bevacqua *et al.* (2011) performed a meta-analysis, relating reported natural mortality to local stock density, annual average water temperature and individual's body mass. According to this meta-analysis, natural mortality can be extremely high shortly after immigration (over 0.3 per annum), and then declines to very low levels (ca. 0.01 per annum) – with lifetime mortality ending up in the same order of magnitude as Dekker's assumption. It is generally believed, that (lifetime) natural mortality might be related to density, longevity, temperature, etc. Since there are very few studies actually evaluating the level of natural mortality, we note that there is no ground to assess any of these relationships. As such, we applied a conservative assumption, that lifetime natural mortality is constant ($\Sigma M=1.5$), for all case studies and for both donor and recipient areas.

There is some evidence, that the actual natural mortality in the field might be lower than $\Sigma M=1.5$. Dekker (2012, finding M in the range of 0.05 – 0.1 per annum, approx. $\Sigma M\approx1.0$. , whilst Rosell (pers.comm.) reported natural mortality as low as $\Sigma M\approx0.25$ for Lough Neagh (UK)). Both estimates are based on the fate of quantities of stocked eel, which may already have incurred a major juvenile mortality before the time of their release. Obviously, as advocated previously by ICES, further research will be needed to derive better estimates of lifetime natural mortality. In the meantime, the current analysis is not so sensitive to the absolute level of natural mortality, but to differences in lifetime anthropogenic mortalities between areas.

5.3.3 Results

Given a total of 6 different sources and 6 different destinations, a total number of 36 scenarios have been evaluated (Table 2). For each of these scenarios, the rate of change in the silver eel escapement has been estimated. Overall, almost all scenarios appear to result in a net loss in the production of silver eel escapement, except for those scenarios taking their glass eel from areas of high anthropogenic mortality, releasing them into areas of low anthropogenic mortality (unexploited), and inflicting a low handling mortality. In most cases, a reduction of the anthropogenic mortality in the source area might constitute a more direct approach to increase the overall silver eel escapement. Where such a reduction turns out to be unachievable for other reasons, translocation of the young recruits might be an option.

Transporting young recruits across a barrier within a river system (assisted migration) appears to create no net-benefit in any case. However, assisting migration does make habitats available to the eel, and maintains a natural eel population in those habitats. Whether or not access to these habitats will actually increase the net production of silver eel escapement, will need to be proven in each individual case.

5.3.4 Scenario conclusions

The current assessment of the net-benefit of stocking and assisted migration is based on information about case-specific lifetime anthropogenic mortality, while values of natural mortality where synchronised for all sites, and where omitted from net benefit calculations this way.

The routine stock assessments reported every third year to the European Commission provide some information on the anthropogenic mortality (as used here though note

Section 2.4), allowing a process of (further) scrutinising and standardisation of the estimation process.

For the (lifetime) natural mortality, however, there is generally little information available, and there are no reporting obligations.

As a consequence, the knowledge base for the assessment of the net-benefit of stocking actions is extremely weak.

It is therefore recommended to improve the knowledge on (lifetime) natural mortalities, including its spatial variation and the relation to case-specific (local) conditions.

Until such research has been undertaken, there is no basis for the evaluation of individual stocking cases, other than the general, conservative assessment given here (Table 2).

5.4 Conclusions

- Lack of any controls used in these studies or a simultaneous assessment of the life history of those glass eel left *in situ* are significant knowledge gaps
- The contribution to spawning of silver eel, derived from stocked eel, is still not quantifiable and is limited by the lack of knowledge on the spawning of ***any*** eel.
- The routine stock assessments reported every third year to the European Commission provide information on the anthropogenic mortality.
- For the (lifetime) natural mortality, there is generally little information available, and there are no reporting obligation to provide this.
- As a consequence, the knowledge base for the assessment of the net-benefit of stocking actions is extremely weak.
- It is therefore recommended to improve the knowledge on (lifetime) natural mortalities, including its spatial variation and the relationship to case-specific (local) conditions.

Until such research has been undertaken, there is no basis for the evaluation of individual stocking cases.

Table 2. Net benefit (green) or loss (red) of translocating young eels from a number of donors to a number of recipients, expressed as a rate of change in the production of silver eel escapement biomass from those young recruits, i.e. $ln\left({}^{gain}/_{loss}\right)$.

For both donors and recipients, estimates of the total anthropogenic mortality ∑A and the total natural mortality ∑M over the lifetime from young eel (relocated or not) to escaping female silver eel are specified. For the donor, an estimate of the handling mortality during catch, holding, transport and release is also given.

	Anthropogenic mortality	Natural mortality	Hand net	Fast stow net	Slow stow net	Stow net, direct	Stow net, ongrown	Assisted migration	←**Sources**
			1.50	0.56	0.94	0.63	0.63	0.00	Anthrop. mortality
				1.50	1.50	1.50	1.50	1.50	Natural mortality
Destinations ↓			0.13	0.58	0.32	0.15	0.30	0.10	Handling mortality
Lake, fished, hydropower	1.10	1.50	**-1.23**	**-1.12**	**-0.48**	**-0.62**	**-0.77**	**-1.20**	
Fished lake	0.69	1.50	**-0.82**	**-0.71**	**-0.07**	**-0.21**	**-0.36**	**-0.79**	
Fished river/lake	0.96	1.50	**-1.09**	**-0.98**	**-0.34**	**-0.48**	**-0.63**	**-1.16**	
Unfished river	0.10	1.50	**-0.23**	**-0.12**	**0.52**	**0.38**	**0.23**	**-0.20**	
Unfished lake/lagoon	0.00	1.50	**-0.13**	**-0.02**	**0.62**	**0.48**	**0.33**	**-0.10**	
Land-based usage	∞		**-∞**	**-∞**	**-∞**	**-∞**	**-∞**	**-∞**	

6 Research needs in order to establish the net benefit of stocking

WKSTOCKEEL has reviewed the current relevant literature on eel stocking and this report has been compiled by the leading experts in the field. We note that some former scientific concerns about eel stocking have now been addressed but there are still a range of knowledge gaps.

WKSTOCKEEL recommends that these Research Needs are highlighted to WGEEL in order to progress the design of approaches to examine the highest priority knowledge gaps (including methods, expertise, situations required, and the identification of potential funding mechanisms).

The following are recommended research needs to address the identified knowledge gaps:

Glass eel/elver/juvenile eel

- Assessments of carrying capacity estimates of glass eel donor estuaries are absent; these are fundamental in denoting any "surplus".
- A whole eel distribution approach to assessing, lifetime mortality, stocking and determining net benefit to the stock (such as the current French project (Section 4.4.1)). Studies must incorporate:
    - i. Appropriate experimental controls;
    - ii. Evaluation of the mortality of the stocked fish;
    - iii. Evaluation of the mortality of the cohort left *in situ*;
    - iv. Development and growth of both cohorts over time.
- Detailed mortality estimates within the commercial stocked eel trade channels.

Silver eel

- Further research into silver eel migration including:
    - i. Observe and measure actual spawning;
    - ii. Assess the reproductive fitness and spawning contribution of silver eels from stocking programs and those of native-origin;
    - iii. Further development of origin identification methods to assist with the above.

7 Overall Conclusions

The conclusions from this WKSTOCKEEL echo many of those from the most recent reviews by Pawson, (2012) & WGEEL (2011) and reiterate the latest advice and recommendations from ICES (2015); (Section 1.5) given that many of their concerns remain unaddressed.

- There have been a significant number of studies examining the outcomes of stocking and as found previously they provide further evidence that translocated and stocked eel contribute to yellow and silver eel production in recipient waters.

- However as noted previously the studies lack controls and/or a simultaneous assessment of the life history of those glass eel left *in situ*. This in effect means that, whilst a local benefit may be apparent, an assessment of net benefit to the wider eel stock is unquantifiable.
- It was difficult to find any data (on any metric) that was directly linked to commercial stocking operations.
- For other aspects (e.g. performance of stocked eel) the published data showed a wide range of results; in many cases no factors were listed which may explain these variations.
- Whilst the natural mortality at the glass eel stage is considered by some to be of the order of magnitude of 0.01, there is enormous variation across EU anthropogenic mortalities ranging from close to zero – 4.
- For the (lifetime) natural mortality, there is generally little information available, and there are no reporting obligations. As a consequence, the knowledge base for the assessment of the net-benefit of stocking actions is extremely weak.
- Ultimately the success of a stocking programme will be judged on the ability of resultant silver eels to contribute to future generations. Whilst concerns over the negotiation of migratory pathways have been reduced the contribution of stocking derived silver eel is still not quantifiable and is limited by the lack of knowledge on the spawning of ***any*** eel.

As a consequence of the above conclusions, the knowledge base for the assessment of the net-benefit of stocking is extremely weak. Until such research needs to address the knowledge gaps have been undertaken, there is no basis for the evaluation of individual stocking cases.

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Annex 1: The eel's life cycle

European eel life history is complex and typical among aquatic species, being a long-lived semelparous and widely dispersed stock. The shared single stock is panmictic (Palm *et al.*, 2009) and data indicate the spawning area is in the southwestern part of the Sargasso Sea and therefore outside Community Waters (McCleave *et al.*, 1987; Tesch and Wegner, 1990). The newly hatched *leptocephalus* larvae use ocean currents to drift to the continental shelf of Europe and North Africa where they metamorphose into glass eels and enter continental waters. The growth stage, known as yellow eel, may take place in marine, brackish (transitional), or freshwaters. This stage may last typically from two to 25 years (and could exceed 50 years) prior to metamorphosis to the silver eel stage and maturation. Age-at maturity varies according to temperature (latitude and longitude), ecosystem characteristics, and density-dependent processes. The European eel life cycle is shorter for populations in the southern part of their range compared to the north. Silver eels then migrate to the Sargasso Sea where they spawn and die after spawning, an act not yet witnessed in the wild. (ICES, 2014b).

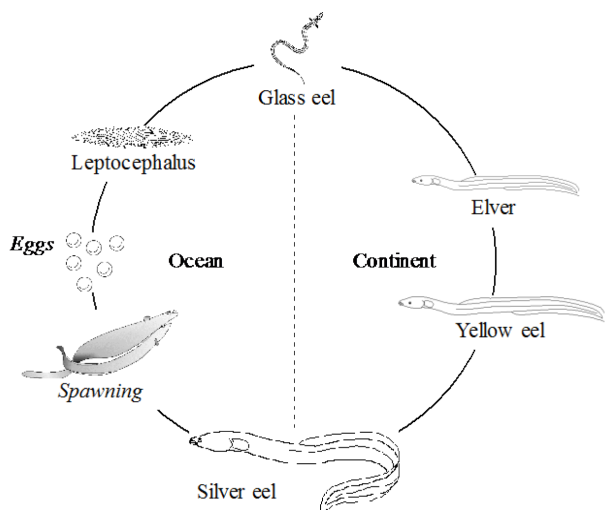

Figure 1. The lifecycle of the European eel. The names of the major life stages are indicated; spawning and eggs have never been observed in the wild and are therefore only tentatively included. (Dekker, 2002).

Annex 2: Glossary of Terms

Glossary

Bootlace	Intermediate sized eels, approx. 10–25 cm in length (fingerlings). These terms are most often used in relation to stocking. The exact size of the eels may vary considerably. Thus, it is a confusing term.
Eel Management Unit (Eel River Basin)	"Member States shall identify and define the individual river basins lying within their national territory that constitute natural habitats for the European eel (eel river basins) which may include maritime waters. If appropriate justification is provided, a Member State may designate the whole of its national territory or an existing regional administrative unit as one eel river basin. In defining eel river basins, Member States shall have the maximum possible regard for the administrative arrangements referred to in Article 3 of Directive 2000/60/EC [i.e. River Basin Districts of the Water Framework Directive]." EC No. 1100/2007.
Elver	Young eel, in its first year following recruitment from the ocean. The elver stage is sometimes considered to exclude the glass eel stage, but not by everyone. To avoid confusion, pigmented 0+cohort age eel are included in the glass eel term.
Escapement (silver eel)	The amount of silver eel that leaves (escapes) a water body, after taking account of all natural and anthropogenic losses.
Glass eel	Young, unpigmented eel, recruiting from the sea into continental waters. WGEEL consider the glass eel term to include all recruits of the 0+ cohort age. In some cases, however, also includes the early pigmented stages.
Non-detriment finding (NDF)	the competent scientific authority has advised in writing that the capture or collection of the specimens in the wild or their export will not have a harmful effect on the conservation status of the species or on the extent of the territory occupied by the relevant population of the species
Ongrown eels	Eels that are grown in culture facilities for some time before being stocked.
Silver eel production	The amount of silver eel produced from a water body. Sometimes referred to as escapement + anthropogenic losses, or production-anthropogenic losses = escapement.
River Basin District	The area of land and sea, made up of one or more neighbouring river basins together with their associated surface and groundwaters, transitional and coastal waters, which is identified under Article 3(1) of the Water Framework Directive as the main unit for management of river basins. The term is used in relation to the EU Water Framework Directive.
Silver eel	Migratory phase following the yellow eel phase. Eel in this phase are characterized by darkened back, silvery belly with a clearly contrasting black lateral line, enlarged eyes. Silver eel undertake downstream migration towards the sea, and subsequently westwards. This phase mainly occurs in the second half of calendar years, although some are observed throughout winter and following spring.
Stocking (restocking)	Stocking or translocation (formerly called restocking) is the practice of adding fish [eels] to a waterbody from another source, to supplement existing populations or to create a population where none exists.
To silver (silvering)	Silvering is a requirement for downstream migration and reproduction. It marks the end of the growth phase and the onset of sexual maturation. This true metamorphosis involves a number of different physiological functions (osmoregulatory, reproductive), which prepare the eel for the long return trip to the Sargasso Sea. Unlike smoltification in salmonids, silvering of eels is largely unpredictable. It occurs at various ages (females: 4–20 years; males 2–15 years) and

	sizes (body length of females: 50–100 cm; males: 35–46 cm); (Tesch, 2003).
Yellow eel (Brown eel)	Life-stage resident in continental waters. Often defined as a sedentary phase, but migration within and between rivers, and to and from coastal waters occurs and therefore includes young pigmented eels ('elvers' and bootlace). Sometimes is also called Brown eel.

Annex 3: List of participants

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Annex 4: Agenda

AGENDA FOR WKSTOCKEEL 20–24 JUNE 2016 TOOMEBRIDGE, UK

Sunday 19 June arrivals and to hotels

Monday 20 June

12 – 1pm: register @ LNFCS HQ

1 – 2pm Lunch on site at LNFCS HQ

2 – 3.30pm Meeting opens: Introductions: discussion of ToR, plan of work /agenda

3.30 – 4pm coffee

4 – 6pm Presentations related to Stocking

Tuesday 21 June

9-10.30am continue presentations related to Stocking

10.30-11.00am coffee and tour of Fishery premises by LNFCS staff

11.00-1pm final presentations related to Stocking

1-2pm Lunch on site at LNFCS HQ

2-3.30pm: discussion of presentations /division into break out groups with specific written tasks

3.30-4pm coffee

4-6pm break out groups with specific written tasks

Evening: Group dinner organised for Restaurant in Castledawson time TBC

Wednesday 22 June (note earlier start time)

8-10.30am break out group writing

10.30-11.00am coffee

11.00-1pm break out group writing

1-3.30pm Lunch: combined with boat trip onto Lough Neagh to see eel fishing

3.30pm: a quick coffee…

3.45-6pm break out group writing

Thursday 23 June

9-10.30am break out group writing

10.30-11.00am coffee followed by group Plenary

11.00-1pm break out group writing

1-2pm Lunch on site at LNFCS HQ

2-3.30pm: break out group writing

3.30-4pm coffee

4-7pm compilation of draft Report

7pm Eel supper and Irish whiskey tasting @ Cross Keys Inn, hosted by LNFCS

Friday 24 June

9-10.30am Circulation of draft report

10.30-11.00am coffee

11.00-1.30pm Group edit of draft Report & Workshop closure

1.30-2pm Lunch on site at LNFCS HQ

Annex 5: WKSTOCKEEL Terms of Reference

Workshop on Eel Stocking (WKSTOCKEEL)

2015/2/SSGEPD08 A **Workshop on Eel Stocking** (WGSTOCKEEL), chaired by Derek Evans*, United Kingdom, will meet in Toomebridge, Northern Ireland, UK, 20–24 June 2016 to:

a) Review and consider recent research into the net benefit of stocking eel for contributing to the spawning stock, including updating recent reviews (including ICES 2013 & Pawson 2012) and prepare a review paper for a scientific journal if appropriate;

b) Identify knowledge gaps currently preventing a definitive determination of the net benefit of eel stocking (see a), and prioritise these gaps in terms of their impact on the uncertainty of net benefit;

c) Design approaches to address the highest priority knowledge gaps (b), including methods, expertise and situations required, and identify potential funding mechanisms;

d) Draft proposals for funding support to address these highest priority knowledge gaps (c).

WKSTOCKEEL will report by 1 August 2016 (via SSGEPD) for the attention of WGEEL, WGRECORDS, SCICOM and ACOM.

The findings of the Workshop will also be of interest to DG MARE and DG ENV, as well as national governments supporting eel conservation, and stakeholders involved in eel stocking.

Supporting information

Priority	This topic is a high priority for ICES because the absence of definitive knowledge accounts for some of the uncertainty in the European eel stock assessment that ICES uses as the basis for advice to the European Commission in addressing the annual requirements of the MoU between ICES and the EU.
Scientific justification	At least 13 countries are engaged in the eel stocking process, either as donors, recipients or both. Stocking can be for the purpose of supporting fisheries, mitigating or offsetting other anthropogenic impacts, or generally contributing to national Eel Management Plans (EMP) to increase silver eel escapement biomass to achieve national targets set by the EU Recovery Plan (EC 1100/2007). Stocking requires that glass eel seed are caught from donor estuaries and rivers and then transported to recipient stocking sites that can be in the same river basin or in a different country. There is often a disconnect between the time glass eel are available and the time when the recipient basins are suitable for stocking, e.g. ice bound northern rivers/lakes, and in such circumstances the glass eel may be held in rearing facilities for several weeks until water temperatures rise. The consequences of such retention on subsequent life history choices are uncertain.

	Stocking can be very expensive because seed glass eel can cost several hundred euros per kg, with 1kg containing about 3000 glass eels. Where stocking is implemented in an EMP for stock conservation purposes, the costs can be supported by European finance (EMFF). The net benefit of stocking for the purposes of stock conservation is defined as where the stocking results in a higher silver eel escapement biomass than would have occurred if the glass eel seed had not been removed from its natural (donor) habitat in the first place. Reviews of the scientific basis of eel stocking (ICES 2013) concluded that there is evidence that translocated and stocked eel can contribute to yellow and silver eel production in recipient waters, but that evidence of further contribution to actual spawning is limited (by the general lack of knowledge of the spawning of any eel). To date, there continues to be significant debate as to whether the stocked eel constitute a net benefit in terms of increasing the spawning stock biomass.
Resource requirements	The host institution will resource the meeting itself. Attendees will be self-funding.
Participants	The Group will be attended by scientists engaged in the research, management and conservation of European eel.
Secretariat facilities	The standard support for arranging the meeting, providing access to sharepoint, and for formatting the report.
Financial	No financial implications.
Linkages to advisory committees	Links to ACOM as eel stocking is a significant management measure of some national eel management plans and is to be taken account of in the international stock assessment of European eel and the associated stock status advice from ICES to the European Commission.
Linkages to other committees or groups	The findings will be of direct benefit to the WGEEL, and wider to WGRECORDS.
Linkages to other organizations	The findings will be of direct interest to DG MARE and DG ENV of the European Commission, the EU CITES Scientific Review Group (SRG), and national governements and stakeholders.

Annex 6: Summary of presentations

Presentations Monday 20th June

Pat Close
(CEO Lough Neagh Fishermen's Cooperative Society)

Welcome:
The Use of Stocking on Lough Neagh

1. Willem Dekker & Laurent Beauloton

History of eel restocking

Young eel, recruiting from the ocean towards Europe, are most abundant along the Atlantic coast of France. Since 1840, attempts have been made to redistribute them from the areas of highest abundance to other countries and farther inland. This 'restocking' has been troubled by technical constraints (e.g. mode of transport and maximum distance eel can be shipped alive), wars (e.g. the Franco–Prussian War and World Wars One and Two) and, in recent decades, by shortage of supply due to the general decline of the eel stock all across Europe. Though objectives and procedures have changed considerably over the years, the recurring aim has been to increase production and, in that way, to 'faire mieux que la nature'. We document the historical development of these efforts from their inception, and contrast the achievements to the objectives. Except for the 1952–1990 period in Eastern Europe, restocking has probably added only slightly to the natural production. As successful as restocking might have been locally, it has not markedly changed the overall trends and distribution patterns or halted the general decline of the stock and fishery. Poor post-evaluation, frequent technical innovation and a constant renewal of the countries and people involved have kept the promise of a better future alive for 175 years.

2. Michelle Allen, Robert Rosell & Derek Evans

Updating eel input to output analyses from Lough Neagh eel data, 1960 to 2014

Lough Neagh, Northern Ireland, is the site of a major eel fishery, managed by a fishermen's co-operative since 1964. Fishing takes place for yellow eels in a 393 KM2 shallow eutrophic lake . Since 1930, the local glass eel immigration to L Neagh via the River Bann has been partially trapped as water level control gates, a weir and Navigation Lock. Traps built at the first weir from the sea enable a trap and transport operation to carry immigrating glass eel to Lough Neagh. The lake has been subject to supplemental stocking with glass eel from elsewhere (Predominantly Severn Estuary. England) since 1983. Good time series exist documenting both these inputs since the fishermen's co-operative formed. Additionally, annual fishery output data exist of yellow eel caught in the lake and silver eel trapped in the out-flowing river Bann. The silver eel fisheries have been subject to mark-recapture efficiency estimates which enable calculation of escapement rates of silver eel. Data is alos available from fishery marketing splits to small (male) and large (females) silver eel.

Silver and yellow eels have been aged to show average (mean) lags of 12 years post Glass eel for silver males, 15 for yellow females (co-operative market size of cm) and 17 for silver females. These known lags allow phase shifting of the outputs for each of these components and reconstruction of output values for individual input year cohorts

The combination of these data allows modelling of input – output relationships by number of individual eel with an effective time series of 38 points. The resultant output yields a density dependent individual survival rate curve, with a good fit to a negative exponential, survival per input eel declining from 0.8 to 0.1 with stocking density rising from 100 to 800 glass eels per hectare.

Further to previously presented analyses, it has now been possible to separate the years with Non-Local glass eel stock added to the local river Bann trap and transport supply. This permits (albeit with limited numbers of data points) separate plots comparing the survival rates of annual cohorts containing non local glass eel with those of only local material. This approach to the data suggests that the Non Local stock has contributed to total eel output, but with a somewhat lower return per glass eel than the local (Bann) trap and transported material. The data series for stocked cohorts is as yet too short to allow definitive conclusions on the actual differential between local and non local imported material. One major concern is the knowledge that while in recent years the trap and transport is the vast majority of natural local supply, there were high input years in the early part of the time series where significant quantities of glass eel migrated naturally to Lough Neagh up the river Bann, an aspect of the data tending to exaggerate the apparent differential between performance of the two input sourced glass eel.

An exponential curve, $y=ae^{-bx,}$ was fitted where y is the proportion of survival to silver, x is the number of glass eels per hectare, and a and b are parameters. The density dependency relationship was assessed for parallelism between years when stocking and no stocking occurred. Separate curves were optimal for the stocked and no stocked years indicating different rates of decay (b) and the constant (a).

Significant (Mann-Kendall, $P<0.05$) monotonic decreasing trends were detected for natural biomass (1960–2015), and yellow and silver eel biomass (1965–2015); and, increasing for mean May-September water temperature at a depth of 10m (1968–2015) and additional purchased biomass (1960–2015). Time series diagnostics confirmed the natural and additional purchased biomass, and the yellow and silver eel biomass were not stationary. Mean May-September water temperature at a depth of 10m was borderline stationary. It was concluded that mean May-September water temperature at a depth of 10m may have undergone a step change or it could be part of a longer cyclic time series.

The natural and additional purchased glass eel biomass, and yellow and silver eel biomass were pre-whitened prior to cross-correlation analysis. The mean May-September water temperature at a depth of 10m was not pre-whitened. The cross-correlation analysis showed significant positive cross-correlation between yellow eel biomass and additional purchased biomass at lag 15; and, significant positive cross-correlation between silver biomass and natural biomass at lag 11 and additional purchased at lags 7 and 8, and negative cross-correlation with additional purchased at lags 10, 14 and 18 and yellow eel output at lags 1 and 2.

The cross-correlation analysis and expert knowledge of the fishery was used to determine what explanatory variables to bring forward for assessment when applying stepwise multiple linear regression to develop models to predict yellow and silver eel catch biomass.

At 20% level of significance the explanatory variables, in order of importance, for the yellow eel biomass model were effort, natural biomass at lags 15 and 14, additional purchased at lag 16, mean May-September water temperature at a depth of 10m, and natural biomass at lag 13. Although not significant (P>0.2) the explanatory variables of additional purchased biomass at lags 13, 14 and 15, and natural biomass at lag 16 were also included. The model explained 85% of the variability within the data and the residuals were stationary. Model predictions from 2016 to 2020, taking account of additional purchased biomass and testing the scenario if no additional purchased had occurred, showed increased yellow eel biomass with stocking from 2018 to 2020.

At 20% level of significance the explanatory variables included in the silver biomass model, in order of importance, were natural biomass at lag 17, additional purchased at lag 8, natural biomass at lags 18 and 8, yellow biomass at lag 1, mean May-September water temperature at a depth of 10m at lag 0, and additional purchased at lags 17, 19 and 18. Although not significant (P>0.2) additional purchased at lag 19 was also included. The model explained 88% of the variability within the data and the residuals were stationary. Using the model to predict silver eel biomass from 2016 to 2020 showed no substantial increase to the silver eel fishery when stocking.

The predictive models need to be further developed.

Continuation of presentations Tuesday 21st June

4. Uwe Bramick

Eel Stocking is essential

River Havel is a tributary to the River Elbe drainage, the second largest river drainage in Germany and draining into the North Sea. Inspired by the re-launch of an extensive stocking program starting in 2006, we aimed to quantify the contribution of stocking to reach the silver eel escapement target value in the River Havel. Therefore, we applied various methodical approaches to study population parameters as recruitment, growth and mortality in order to foster the application of the German Eel Model III (GEM III) for calculation of current silver eel escapement with and without anthropogenic impacts. While minimum values of 0.09–0.17 kg/ha (equivalent to 32,000–55,000 individuals) were modelled for the period 2011–2013, values exceeding the escapement target (calculated at 1.2 kg/ha) were projected to be reached from 2016 onwards. At the same time, Bbest is calculated to reach values decreasing from 0.4 kg/ha (2016) to 0.1 kg/ha (2023) for 2016. In conclusion, the silver eel escapement target in the River Havel cannot be reached without a considerable amount of stocking. This constellation is likely to apply to other Eel Management Units with low current natural immigration values as well, and might be considered a key dilemma in eel management.

5. Hakan Wickstrom & Willem Dekker

Monitoring of Swedish stocked eel populations / Estimating M from catches in Sweden

Wickström & Dekker presented data on the present stocking program in Sweden. All eels stocked are since 2009 marked chemically with strontium chloride in their otoliths. Besides stocking in Sweden also eels for stocking in Finland come from the same source (a Swedish quarantine/aquaculture facility) and thus are marked using the same method. In total more than 15 million marked have been stocked so far, mostly in freshwater but in considerable numbers also in brackish/marine environments. Some examples, from fresh as well as from marine waters, on the value of marking were presented. The results do not indicate any significant difference in growth between stocked eels and eels originating from natural recruits. Finally, a theoretical calculation on natural mortalities in different lakes were presented. By comparing the actual catch with an estimated output based on stocking and natural recruitment it was concluded that the natural recruitment in stocked eels must be much lower than normally assumed. Estimates as low as $M \leq 0.10$ per annum were given.

6. Marko Freese, Roxana Sühring,, Jan-Dag Pohlmann, Hendrik Wolschke, Victoria Magath, Ralf Ebinghaus, Reinhold Hanel

A question of origin: dioxin-like PCBs and their relevance in stock management of European eels

Stocking or reallocation of eels in suitable habitats is one of three major management (besides limiting fisheries and improvement of fish migration) options for authorities to reach the targeted 40% silver eel escapement goals as postulated for the national Eel Management Plans in European Council Regulation (EC) No 1100/2007. Spawner quality of mature eels in terms of health status and fitness is considered one of the key elements for successful migration and reproduction. While a number of chemical contaminants have been described in literature to negatively affect overall health and fitness of fish. Dioxin-like Polychlorinated Biphenyls (dl-PCBs) are known persistent organic pollutants potentially affecting the reproductive capability and health status of eels throughout their entire lifetime.

In our study, we analysed eels of all continental life stages from 6 different water bodies and 13 sampling sites for contamination with lipophilic dl-PCBs to investigate the potential relevance of the respective habitat in light of eel stock management. Our results reveal habitat-dependent and life history stage-related accumulation of coplanar PCBs. Sum concentrations of targeted PCBs differed significantly between life stages and differences in contaminant levels and -profiles among different water bodies was observed. Migrant silver eels were found to be the most suitable life history stage to represent their particular water system due to habitat dwell-time and their terminal contamination status.

With reference to a possible negative impact of dl-PCBs on health and the reproductive capability of eels, we conclude logically that those growing up in less polluted habitats have a better chance to produce healthy offspring than those growing up in highly polluted habitats. We suggest that the contamination status of water systems is fundamental for the life cycle of eels and needs to be considered in stock management and restocking programs.

7. Laurent Beaulaton

3 Years of French eel stocking research& New French Stocking project

An expertise (Rigaud *et al.*, 2015) involving 10 scientific experts during 4 months examine the outcome of 3 years (2011–2013) of the French National restocking program. This program is based on public tender that includes monitoring. During those years, 28 projects restocked 6768 kg of glass eels for a total budget of millions euros. The expertise examines factors that influence the quality of glass restocked and try to evaluate the survival of them after 3 years. Finally recommendations to improve restocking itself and monitoring are made. The final report is available:

http://www.onema.fr/Le-programme-francais-derepeuplement-en-civelles

8. Rigaud, C., Beaulaton, L., Briand, C., Charrier, F., Feunteun, E., Mazel, V., Pozet, F., *et al.* 2015. Le programme français de repeuplement en civelles. Bilan des trois premières années de transferts. Rapport d'expertise. GRISAM.

French ongoing experiment on restocking

A 3 years' program, involving Onema, Inra and MNHN and funded by the French ministry, has just started. Its aim is to compare restocking protocol used in Europe and to set up an experiment to study the early (3 month) survival of both natural and stocked glass eel. During the workshop the principle of theses experiments are presented.

Contact: Laurent Beaulaton, Pôle Gest'Aqua Onema-Inra, laurent.beaulaton@onema.fr

9. John Taylor

Llangorse Lake local eel stocking project. Efficacy of stocking different life stages

Several past ICES/EIFAC Working Groups on Eel have highlighted the need to determine the most cost effective stocking strategy for juvenile eels to ensure the most efficient use of a scarce resource. Natural Resources Wales have attempted to address this knowledge gap by carrying out experimental stocking in Llangorse Lake, near Brecon. Llangorse Lake is a shallow eutrophic natural lake know for eel production, it has a silver eel trap on the exit river LLynfi. Juvenile eels were stocked from 2011–2016 either as pigmented elvers direct from the supplier or on-grown at the NRW's culture station, near Brecon, for 9 months. All stocked eels were either chemically marked with strontium chloride or physically marked with coded wire tags (CWT). Background data was collected on historical silver eel catches and the trap was selectively fished to assess the current levels of adult eel escapement. Very small numbers of adult eels have been captured annually since 2011 suggesting that there has been an historical lack of recruitment. The first emigration of stocked eels is expected within the next couple of years.

10. Reinhold Hanel

Translocation of eels into freshwaters: a management tool without impact?

Since eels are frequently moving through a variety of different habitats during their life cycle, a better understanding of the implications of individual diadromous behaviour and habitat choice on spawner quality are crucial for management considerations for a stock recovery. To test whether individual migratory behaviour and habitat choice of European eels affect spawner quality, the migratory behaviour of 287 European eels from marine, brackish and freshwater stations in the North Sea, the Baltic Sea and from Northern German inland waters was examined by otolith strontium/calcium analysis (Marohn *et al.* 2013). All individuals were classified either as freshwater residents, coastal residents, downstream shifters, upstream shifters or interhabitat shifters. As indicators for eel quality, muscle fat content, infection with the introduced swimbladder nematode *Anguillicoloides crassus* and body length at onset of spawning migration were assessed. Results indicate that individuals that exclusively inhabited freshwaters had significantly lower muscle fat contents and were more seriously infected with A. crassus than eels that never entered freshwaters. Since high fat contents are considered as prerequisites for a successful transoceanic spawning migration and high A. crassus loads have a negative impact on condition, this study outlines the importance of brackish waters as eel habitats in temperate latitudes. Furthermore, it questions the net benefit of stocking programs for the European eel population, since they include the translocation of eels from coastal waters into freshwaters.

In a second study, total female silver eel escapement from a northern German drainage system (Schwentine River) was assessed over a period of three consecutive years, and downstream migration patterns were compared to potential environmental triggers (Marohn *et al.*, 2014). The results indicate that silver eel escapement from the Schwentine drainage system is far below the estimated values underlying the respective eel management plan, highlighting the necessity of direct migration assessments to validate indirect estimations that include multiple assumptions and uncertainties. Major downstream migration events took place during short time periods in autumn and appear to be influenced by river discharge and water temperatures, suggesting that a precise prediction of escapement events is possible. Regarding spawner quality, fat reserves appear sufficient for escaping silver eels to migrate and spawn. However, high A. crassus prevalence and infection intensities are assumed to further reduce the number of potential spawners. As a consequence, 2 310 500 glass eel equivalents have been Baltic Sea coastal waters as glass or ongrown eels since 2013 in Schleswig-Holstein.

11. Michael Pederson

Danish pond eel stocking experiments

To evaluate the efficiency of eel stocking program, we compared the relative survival and growth of wild eels caught in a river with that of eels obtained from an eel farm. Two experiments were carried out in 200 m^2 semi-natural drainable ponds. The initial eel density was 0.5 individuals/m^2. Eels were 3–5g when stocked. Both types of eels were offered similar conditions, concerning handling, tagging, density, food availability and predation. After one growth season (5 months) survival was equal for the two types of eel but farmed eels had a significant higher growth rate than wild eels. The ontogenetic development of the two types of eel used in the study may have influenced the result, but it is clear that stocked (farmed) eels performed very well in this study.