European eel and aquaculture

Kirkegaard, Eskild; Aarestrup, Kim; Pedersen, Michael Ingemann; Jepsen, Niels; Kirkegaard, Eskild; Koed, Anders; Larsen, Erling; Lund, Ivar; Tomkiewicz, Jonna

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DTU Aqua Report No 229-2010

By Eskild Kirkegaard (ed.)

DTU Aqua
National Institute of Aquatic Resources

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The following have contributed to the report:

Kim Aarestrup
Michael Ingemann Pedersen
Niels Jepsen
Eskild Kirkegaard
Anders Koed
Erling Larsen
Ivar Lund
Jonna Tomkiewicz

DTU Aqua
National Institute of Aquatic Resources

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1 Introduction

The European eel (*Anguilla angiuilla*) stock was very abundant in European waters until thirty years ago. However, the stock has declined drastically during the recent decades. The causes of the decline is believed to be a combination of fishing on the eel in all its continental life stages: glass eels, yellow eels and silver eels, deterioration of habitat including hydropower plants, drainage of wetlands and pollution, climate changes and introduced diseases and parasites. This report provides with focus on the aquaculture of eel an overview of the development in the state of the eel stock, eel fisheries, eel farming, eel management plans and market for eel products, and comments on the sustainable use of European eel.

The catches of yellow eels and silver eels are used for human consumption while glass eels catches mainly are used in aquaculture for production of elvers used in restocking programs and yellow eels for human consumption or directly for human consumption.

1.1 Life cycle of European eel

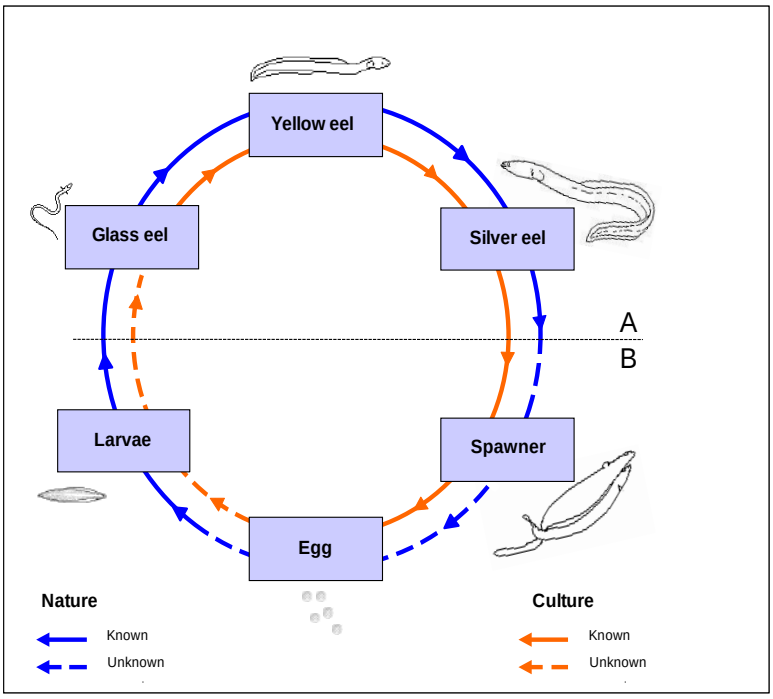


Figure 1 Development stages and phases in the life cycle of eels in nature and aquaculture with indication of known and unknown parts of the cycle. A. Continental phase: freshwater and coastal marine areas, B. Oceanic phase including adult spawning migration to the Sargasso Sea and transportation of leptocephalus larvae with currents to European coasts. (Tomkiewicz, DTU Aqua; modified from Dekker).

The life cycle of European eel can be divided into a continental and an oceanic phase (Fig. 1). The eel is widespread on the European continent, but is believed to spawn in the Sargasso Sea located south east of Bermuda. The earliest larval stages caught in the Sargasso Sea have remains of an oil droplet that is part of the yolksack from the egg. When the larvae start feeding, they transform into transparent leaf-shaped larvae, called leptocephali. The Gulf Stream and North Atlantic Drift current bring the leptocephali larvae from the Sargasso Sea to the North African and the European coasts over a 1 to 2

year period. In the coastal areas the larvae transform into glass eels. A large fraction of the glass eels migrate into freshwaters but some remain in coastal and estuarine waters.

The glass eels grow into elvers and become pigmented. During their continental growth phase they develop into so-called yellow eels named after their yellow-green colour. When the eels are between 6 and 16 years or even older in northerly cold areas, they change appearance as a first step of the maturation process. The head becomes narrower, the eyes enlarge, the colour changes from yellowish to silver i.e. the silvering process. At this life stage, eels are called silver eels. The silver eels migrate downstream towards the sea and towards the Sargasso Sea to spawn. The development of ovaries and testes, become suppressed during silvering. Maturation is likely resumed towards the end of the migration. However, information on eels in this life stage is very limited as maturing or spawning Europeans eels have never been caught in the ocean.

2 Development in stock size and fisheries

2.1 Factors affecting the stock

The eel is in Europe found over a multitude of inland and coastal waters with divergent characteristics. This means that the impact on the eel of anthropogenic and environmental pressures, such as fishing, barriers to migration (including intakes and turbines), pollution, habitat loss, diseases, parasites etc. is very much dependent on the local conditions and large differences in eel quality and mortality occur between areas.

The information on mortality is either missing (egg and larvae stages) or very limited and it is in general not possible to quantify the affect of anthropogenic and environmental pressures on eels.

2.1.1 Fisheries

Fisheries for eel are small scale fisheries scattered throughout the entire distribution area including large parts of Eastern Europe where eels are stocked. The target of the fisheries varies from newly recruited glass eels to silver eels up to 20+ years of age.

The International Council for the Exploration of the Sea (ICES) stated in 2009 that "despite the marked stock decline, fishing effort and mortality continues to be high both on juvenile (glass eel) and older eels (yellow and silver eel). Landings reported to FAO have declined to about 25 % of the annual catches during the mid-1960s, although the reported landings values are known to be unreliable. Decreased landings in combination with continuous high fishing mortality are a strong indication of reduced stock size".

Danish fisheries (commercial and recreational) mainly take place in fjords and coastal waters. Available information indicates that the fishing mortality on silver eels is high in Danish waters (Aarestrup et al. 2008, Aarestrup et al. in press).

2.1.2 Habitat quality

Eel habitats have been reduced substantially both in number and in quality. Wetlands have been drained and river systems regulated with the result of not only losses of habitats but also reductions in quality of the remaining habitats. In Denmark more than 95% of the rivers have been regulated. Many of the regulations include barriers to eel migration.

Recent studies on silver eel migration and survival in the River Gudenå show very high mortality of downstream migrating eel and point losses of 70 - 80 % was observed at Tange Hydroelectric station (Pedersen et al. 2009). If this is representative for mortality associated with passing obstacles in the stream eels may suffer high mortality in many rivers when migrating downstream.

2.1.3 Parasites and diseases

The nematode (*Anguillicoloides crassus*) is a parasite located in the swimbladder of eels. It originates in Asia, but was accidentally introduced in 1980'ies and is now found in the entire distribution areas area of European eel. It is unclear how the parasite affects the eel. It is, however, believed that the main effect is on the silver eels during the spawning migration. Heavy parasite loads may have a negative impact on the condition eels infested and may contributed to the poor state of the stock. The swimbladder parasite seems most abundant in eels caught in freshwater. Eels grown in saline waters tend to have a lower parasite load.

Virus infections, such as EVEX and Herpesvirus anguillae, which have been reported in wild and farmed eels from widely separated parts of the world, may represent a threat to European eel.

2.1.4 Pollution by contaminants

Eels accumulate considerable amounts of contaminants and the body burden of compounds such as PCBs, DDT and dieldrin in eels from many parts of Europe are so high that it may have a negative impact at the population level (ICES 2009).

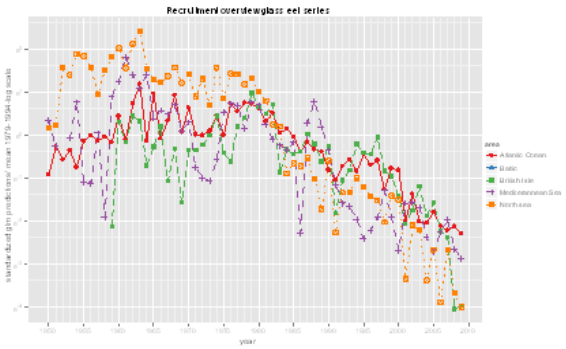
2.2 State of the stock

ICES advised in 2009 that "Abundance of the eel stock for all stages including glass eel, yellow eel and silver eel is at a historical minimum. All glass eel recruitment series available covering the distribution area from the Mediterranean sea in south to the Baltic in the North show clear and marked reductions since the early 1980s (Figure 2). Recruitment is at a historical low level and continues to decline".

The current recruitment of glass eels is in the different geographical areas estimated to be between 1 and 9 % of that observed in the 1970s. Recruitment in 2008 and 2009 has been especially low. Recruitment of continental North Sea yellow eel has been declining continuously since the 1950s. Recruitment of yellow eels in the Baltic is now less than 10 % of that observed in the 1950s and 1970s (Figure 3).

The run of glass eels to Denmark as monitored in three Danish streams follows the general downward trend of Europe and is now very low. The recruitment of yellow eel to Danish streams is less than 5 % of the level observed in the 1970's.

Based on the state of the stock ICES recommends that "all anthropogenic impacts on production and escapement of eels should be reduced to as close to zero as possible until stock recovery is achieved".
Eel is included in the International Union for Conservation of Nature (IUCN) and the Danish red list as "Critically Endangered".



Figur 3 Recruitment index for glass eel per area in logarithmic scale. Each series is scaled to the mean of 1979–1994.

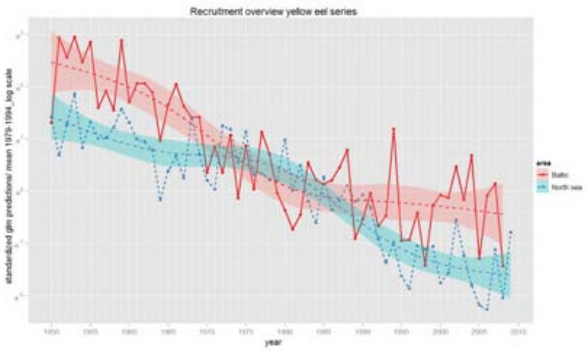


Figure 2 Recruitment index for yellow eel per area in logarithmic scale. Each series is scaled to the mean of 1979–1994. (ICES, 2009)

3 Eel management plan

The European Council adopted in 2007 a framework regulation for the recovery of the stock of European eel (COUNCIL REGULATION (EC) No 1100/2007 of 18. September 2007). The regulation establishes a framework for the protection and sustainable use of the stock of European eel.

Each EU Member State is required to establish eel management plans. The objective of each plan shall be to reduce anthropogenic mortalities so as to permit with high probability the escapement to the sea of at least 40 % of the silver eel biomass relative to the best estimate of escapement that would have existed if no anthropogenic influences had impacted the stock.

The regulation distinguishes between river basins and marine waters. Member States shall for each river basin establish a plan that may include, but not be limited to, the following actions:

- 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 of hydro-electric power turbines,
- measures related to aquaculture.

At least 60 % of the catches of eels less than 12 cm in length must by 31 July 2013 be marketed for use in restocking in eel river basins. At present 45% should be used for stocking.

Where a Member State operates a fishery in Community waters that catches eel, the Member State shall either reduce fishing effort by at least 50 % relative to the average effort deployed from 2004 to 2006 or reduce fishing effort to ensure a reduction of eel catches by at least 50 % relative to the average catch from 2004 to 2006.

The regulation also includes a number of monitoring and reporting requirements including reporting of the amount of eel less than 12 cm in length caught and the proportions of this utilised for different purposes.

The Danish management plan was approved by the commission in 2009. The plan designates the whole territory as one management unit and includes:

Measures in freshwater include:

- a licence system for professional fisheries
- a closed fishing season for amateur fishermen and landowners
- stocking

Measures in marine waters:

- a licence system for professional fisheries
- a closed fishing season for amateur fishermen
- increase of legal size for yellow eel

Stocking forms an important element of the Danish management plan. A total of 16 streams have been proposed to be stocked as part of the management plan. However a recent study (Pedersen 2009a) demonstrates that stocking streams seems less profitable in terms of growth and survival of the released eels compared with stocking of eels in coastal waters such as Roskilde Fjord (Pedersen 2009b), indicating that stocking in coastal waters may be more profitable in growth and survival terms.

4 Development in eel aquaculture

Intensive farming of European eel started some 25 - 30 years ago, and currently supplies approximately 45,000 t /y (worldwide), which is more than 80 % of the worlds consumption of this species (Nielsen and Prouzet, 2008). In addition to the use of farmed eels for human consumption the stocking programs in Northern Europe are relying on farmed elvers and yellow eels.

Most European eels are farmed in Europe and in Asia with approximately 9-10,000 t produced annually in Europe during 1996- 2007 (ICES Advice 2007). The estimated current level is 4-5000 t based on recent statistical reports (Christian Graver, Dansk Åleproducentforening, DÅP, March 2010). Since the 1990s European farming has been dominated by Denmark and Holland.

Most eel farms in northern Europe are based on intensive recirculation technology (introduced in the late 1980s). In Asia eels are mainly reared in semi-intensive still water ponds. In the intensive farms eels are reared at very high densities exceeding 120 kg /m^3 of water and a water use (make-up water) of only 4-8 % of total water volume, due to the implementation of efficient treatment technologies (biofilters etc.). An intensive eel farm with an annual production of 100 t may employ 1-3 persons in Europe. In the semi-intensive farms eels are reared at maximum 20 kg /m^3 and utilize approximately 4,000 m^3/d, a semi intensive farm may employ 20-30 persons for each 100 t production in Asia (Nielsen and Prouzet, 2008).

The ideal temperature range for eels to remain healthy and to efficiently convert feed into growth is 23-28 °C. Temperatures above optimal will result in lowered feeding and reduced growth rates, stress and risk of increased mortality. Growth rates sufficient to reach human consumption market size in 12 months have been reported in Europe, but in average usually 18 months are required. Feed conversion ratios (FCRs) (i.e. kg feed /kg fish produced) is on average 1.6 -1.7 in Europe but ratios as low as 1 have been recorded (Christian Graver, DÅP, March 2010).

5 Development and restraint in the human consumption market for eel and eel products

The European eel was put on the CITES list II the 13 March 2009, with the consequence that all international trade outside EU, needs an export permit from the national authorities. The public awareness of the development of the European eel, lead to a growing demand from NGO's to stop consumption of eels. This resulted in a boycott of eels and eel products after Christmas 2009 in all food shops belonging to Dansk Supermarked (Bilka, Føtex og Netto). This decision was taken in co-operation with WWF. The boycott is covering German and Dutch multiples. 95 % of the Danish eel production is exported, 80 % to Holland. The development in the German market has shown dropping prices of eels.

The average European price on live adult eel just before Christmas 2009 was 8 €/kg ab farm. A campaign against consumption of eels started after Christmas and the price dropped to below 7 €/kg live weight in February 2010. This reduction of more than 20% has made the production in aquaculture unprofitable.

The prices for European glass eels for farming are in 2010 in Europe: 440-660 Euros/kg (season dependent) and in China 850-950 Euros/kg (Peter Wood, UK Glass Eels).

The price of glass eels should preferably stay below 400 Euros to ensure feasibility for farmers in Europe. For European aquaculture app. 2.5 kg of glass eels is needed to produce 1 t of market size human consumption eels (approx. 150 g/piece). 1 kg of glass eels is approximately 2800-3300 individuals (~0.3 g/ind^{-1}).

It is likely that the low price on eels for human consumption will continue in the next years as a result of the lower demand on eel and eel products. This combined with a relative high price on glass eels and elvers, may make the aquaculture production of eels for human consumption unprofitable.

6 Use of glass eels

At present, aquaculture of eels for human consumption and stocking is entirely based on wild glass eels that are caught in target fisheries. The glass eel fishery and handling of the catches are therefore central for the eel production whether the production goes for human consumption or stocking as part of the management plans.

6.1 Glass eel fisheries

Fisheries for glass eels in Europe are carried out by several countries, not all catches are registered and there is no international database on glass eel yield or trade (Dekker, 2004). A significant percent of European catches are exported and reared in Asia, mainly China as illustrated in Table 1. In the early 1990s catches were app 3-500 t/y, but have declined significantly since.

The estimated catches of glass eels in recent years are below 50 t as shown in Table 1.

Year	Total catch of glass eels (t)	Human consumption (t)	Aquaculture and restocking (t)		China as % of total catch
			Europe	China	
1993-1994	350	275	30	45	13
1994-1995	500	385	35	80	16
1995-1996	350	200	40	110	31
1996-1997	320	75	45	200	63
1997-1998	125	35	12	78	62
1998-1999	340	180	40	120	35
1999-2000	230	80	20	130	57
2000-2001	140	20	20	100	71
2001-2002	230	100	25	105	46
2002-2003	220	90	30	100	45
2003-2004	115	27	28	60	52
2004-2005	110	13	22	75	68
2005-2006	92	14	31	47	51
2006-2007	86	17	24	45	52
2007-2008	75	12	22	40	53
2008-2009	36	12	19	5	14
2009-2010*	48	11	15	22	46

Table 1. Estimated catch of glass eels and their utilisation directly for human consumption or for aquaculture including restocking. The estimates are based on information from French, English and Spanish glass eel exporters *Estimated catch and distribution. Source (Christian Graver, DÅP, and Peter Wood, UK Glass Eels March 2010).

The main harvest of glass eels is recorded in the river estuaries along the Atlantic coast and the English Channel (Nielsen and Prouzet, 2008).

6.2 Legal situation

Within the EU the legal use of glass eel is addressed in Article 7 of the EU regulation (COUNCIL REGULATION (EC) No 1100/2007 of 18 September 2007):

1. *If a Member State permits fishing for eels less than 12 cm in length, either as part of an Eel Management Plan established in accordance with Article 2, or as part of a reduction in fishing effort in accordance with Article 4(2) or Article 5(4), it shall reserve at least 60 % of the eels less than 12 cm in*

length caught by the fisheries in that Member State during each year to be marketed for use in restocking in eel river basins as defined by Member States according to Article 2(1) for the purpose of increasing the escapement levels of silver eels.

2. *The 60 % for restocking is to be set out in an Eel Management Plan established in accordance with Article 2. It shall start at least at 35 % in the first year of application of an Eel Management Plan and it shall increase by steps of at least 5 % per year. The level of 60 % shall be achieved by 31 July 2013.*

This means that no later than 2013 60 % of all glass eels catches within the EU shall be used for restocking in EU waters and only 40 % can be used for other purposes including human consumption. The regulation indirectly put limits to the amount of glass eels caught in EU that may be exported to Asia. For practical reasons it is unlikely that eels farmed in Asia can be used for stocking in Europe and the stocking demands will have to be met glass eels or by European farmed eels.

6.3 Use of glass eels in aquaculture

Successful reproduction of European eel has still not been achieved in captivity and aquaculture production of eels is based on natural glass eel production.

A recent research project lead by DTU Aqua, Denmark, has successfully hatched several thousands of prolarvae, but all died before initiation of first feeding. Despite ongoing research projects, a commercial break trough in reproduction may have relatively long time prospects.

While it has so far not been possible to reproduce eel in captivity, using wild glass eels have been a success in aquaculture as they:

1) accept readily the early food offered
2) easy to wean to dry feed with high survival
3) used to be easy to collect, -as utilized for direct human consumption for decades
4) easy to transport, rarely any diseases (parasites, viruses, bacteria)

Glass eels only need a few days to adapt to a rearing system. Temperature is gradually increased to 18-20° C and hereafter feed is introduced, which consist of cod roe (European farms) or red tubifex (Asian farms, China). Red tubifex harvested from rivers may introduce serious disease, though. Glass eels easily accept these feed types and gradually paste or extruded granulates with a high protein content is introduced.

The estimated survival in aquaculture of glass eels from cod roe feeding during weaning to dry feed is 80-90 %. Mortality is highest during this phase and until app. 5 g size. Hereafter mortality is less than 1 %. An overall survival of 75-80 % until human consumption market size is common (Christian Graver, DÅP, March 2010).

6.4 Stocking

ICES advised in 2009 that the use of restocking of eels in the EU Regulation on recovery of the European eel may involve translocation of eels between river basins. ICES further notes that it is unlikely that the 40% recovery objective of the EU Regulation can be met primarily through stocking, since the total catch of glass eels is well below that required to obtain goal set out in the regulation. Moreover, the contribution stocked glass eels make to the future spawning stock will be reduced if: (a) there is some capture and translocation mortality, (b) there are more anthropogenic stresses in the river

system in which they are stocked than in the source river and (c) the stocked eels are not able to migrate to spawning grounds and contribute to the spawning portion of the stock. For these reasons ICES is concerned about the use of glass eels for stocking, and does not endorse this aspect of the EU Regulation. However, recognizing that it is identified as one of the recovery tools in the Regulation, ICES stated that stocking should be limited to unpolluted waters with low pathogen burdens, and exhibiting minimal other anthropogenic impacts, including fishing. Procedures to prevent the introduction and spreading of parasites and diseases should be applied, in accordance with European fish disease prevention policies. ICES underlies that large-scale stocking should not be allowed unless a scientific evaluation demonstrates that the potential escapement of silver eels will be enhanced.

The ICES working group on eel (WGEEL 2009) concluded that the studies reviewed by working group demonstrate that the performance of stocked material in the yellow eel phase cannot be assumed to be as good as that of natural immigrants, but also conversely that it often falls within the ranges of best and worst observations of performance of wild stock.

The few direct comparisons of stocked vs. wild eel growth and survival put the range of relative performance of stocked to wild at between 25% and parity. It is reasonable to assume that the degree of handling and intervention between glass eel and stocking strongly influences the outcome, and that best stocking practice is that which mirrors the local wild component.

There is a lack of information on the outcome of previous stocking exercises in terms survival of stocked material through to eventual escapement of silver eels. WGEEL 2009 therefore recommended that all stocking activity from now on be designed to include traceability of eel into later life stages. The best means of ensuring conclusive traceability is by using batch or other marking methods. OTC alizarin and strontium have all been used successfully to date on glass eel, PIT, CDTs, and other tags for larger stages.

As described in chapter 3 forms stocking an important element of the Danish management plan and 1.6 million elvers (1.3 in freshwaters and 0.3 in coastal waters) have been released in 2010. The streams where releases have taken place have been selected in accordance with ICES recommendations.

6.5 Handling of glass eel – can survival be improved?

Survival of glass eels caught by the fishery for aquaculture is affected by fishing gear and practice, transportation and start feeding.

6.5.1 Catch

Glass eel caught using moving and stationary fishing gears are subject to handling mortality (e.g. in trawls may this be up to 82%) while the mortality of samples collected by handnets or from the trapping ladder may be close to nil (ICES, 2009). Thus, in order to evaluate the potential for improvement of survival of wild caught glass eels, it is necessary to consider how the fishery is preformed performed today. England and France are the principal countries in relation to commercial catches of glass eels (Dekker, 2002). Fisheries and catches in both countries are covered by legislation.

In England, this legislation covers the entire country. Fishermen are only allowed to fish in certain rivers, and at specific times. It is only allowed to fish with handheld nets, the so-called dipnet. In France, the legislation is not national but embedded in each region's law. The time periods where glass fisheries are allowed vary among regions, and the fishing methods allowed in various regions are very

different. In particular and a result of the fishing methods, the survival of glass eels in the catches varies greatly. In northern France (including e.g. the Loire and Vilane) glass eel fisheries apply very powerful motor boats up to 300 HP and nets with a circular opening being drawn fast through the water. The time intervals between emptying the nets are long, which cause that many glass eels are being crushed in the nets and die. In central France (including e.g. Girone) glass eels are fished with pelagic trawls that are drawn slower through the water and the mortality rate in the catches is somewhat less. In southern France (including e.g. the Adour) glass eels are fished with handheld nets using the same principles as in England. The mortality rate is here minimal as in England. (Dekker, 2002)

A reduction of the fishing and handling mortalities would thus lead to more efficient use of the limited and declining resource of glass eels (ICES 2010). A scientific report on the animal welfare aspects of husbandry systems for farmed European eel was published by European Food Safety Authority (EFSA) in 2008 and their recommendations were to use known glass eel capture methods already identified as having fewer, less severe hazards associated with them.

6.5.2 Transport

Today, glass eels are transported partly by road and partly by air freight. Road transport of glass eels takes place in tanks with water and the possibility of oxygen control. The tanks can hold between 100 and 500 kg glass eels per tank depending on size and density. By air glass eels are transported in Styrofoam-boxes. The boxes can hold between 1 and 3 kg of glass eels. Glass eel are "dry", but the box holds a small beaker with ice. This beaker has 2 purposes. It keeps the temperature adequately low and condensation on the outside of the beaker which keeps the glass eels moist. (Christian Graver, DÅP, March 2010).

Transport method is determined solely by the distance that the glass eels need to be transported. For example, all glass eels transported from France to Denmark arrive by truck, while glass eels from England are transported by air freight. Mortality rates in both modes are minimal. In general, the mortality rate is below 0.5% and the potential gain for improvement is limited. Glass eels that die during transport are usually being refunded by the seller. They are returned and sent to the consumer market. (Christian Graver, DÅP, March 2010).

6.5.3 Start feeding

The glass eels are sorted at the arrival at the eelfarm and the ones that died during transport are eliminated. Living glass eels are transferred to tanks with temperate water. Feeding is initiated after a short warming period (1 to 2 days). In the beginning, they are exclusively fed cod roe. With time suitable dry food gradually replaced the cod roe. The highest mortality occurs in relation to the adaptation to dry food. Mortality occurs over a long time period, because glass eels can starve themselves for longer periods of time without dying. The highest mortality rates normally occur around 8 weeks after intake. (Christian Graver, DÅP, March 2010).

The mortality in relation to start feeding has been substantially reduced during the last 20 years, and the increase in growth of glass eels during the first weeks has been radically improved. 20 years ago, there was no growth in the first 8 weeks, and the mortality rate exceeded 50%. Now growth is between 2 and 5% per day and mortality is halved compared to the former level.

The mortality is primarily caused by glass eels never starting on the offered feed in particular dry feed. There are undoubtedly opportunities in future to improve start feeding in spite that many attempts have

been done. The high price of glass eels i.e. between 1 and 2 DKr. makes individual farmers favour new approaches.

6.5.4 Reproduction of eels in captivity

For the aquaculture industry, reproduction of European eel in captivity is of particular interest, given the critical status of the stock. At present, aquaculture of eels for human consumption and restocking is based on glass eels that are caught by a directed fishery. The long term goal for eel aquaculture is therefore to produce glass eels for a self-sustaining farming industry.

European eels migrate to spawning areas in the Sargasso Sea and do not mature in our waters or in captivity (Fig. 1). This is caused by a hormonal inhibition of gonadal development that sets in at the same time as silvering and spawning migration starts. In order to reproduce eel in culture, maturation of females and males is therefore induced by hormonal treatment and fertilisation of eggs is made *in vitro*. Attempts to artificially breed European eel using this method are dating back to the middle of last century, where pioneering work by the Frenchman Maurice Fontaine lead to maturation of male and female eels. Larvae of the related Japanese eel (*Anguilla japonica*) were first obtained in the 1970ies and in the 1980ies, Russian researchers succeeded in hatching and producing yolk sac larvae of European eels living for up to 3.5 days. The experiments with the Japanese eel lead to that glass eels were successfully produced for the first time in 2003 (Tanaka et al., 2003) and in April 2010 Japanese researchers reported that they have successfully produced glass eels from farmed eels and thereby closed the reproduction cycle in captivity. The requirements to obtain a commercial production of glass eels are a present to improve first feeding, on growing and survival of larvae in order to produce healthy glass eels in a cost efficient way for aquaculture purposes.

For European eels, substantial progress has been made in the recent decade within a series of Danish projects lead by DTU Aqua have succeeded in breeding eels and culturing larvae for up to 18 days. During this period, the larvae completed the yolk sac stage, which is a critical period where they completely rely on the nutrition from the egg, and reached the stage where they are ready to start feeding (Tomkiewicz and Jarlbæk, 2008).

Research in reproduction of eels in captivity deals with three main bottlenecks which include: 1) the induction of maturation; 2) induction of ovulation and production of viable eggs; and 3) culture of embryos and larvae. For the European eel, the methods used to induce maturation are still suboptimal and a high percentage of female brood stock fishes fail. Improvement of the brood stock selection and treatment is therefore a focus area. In addition, ripe females do normally not release their eggs spontaneously, and ovulation needs also to be hormonally induced. The hormonal treatment used to induce ovulation often results in infertile eggs or egg that are not viable and therefore need improvement. Once fertilised egg have been achieved the survival rates in culture of eggs and larvae is a new challenge and the establishment of first feeding is in general a difficult step in aquaculture. For eels is it a particular challenge because little knowledge exist about their food in nature and because the larval stage including the leptocephalus stage (Fig. 1) may last one year or more. The first feeding and on growing of larvae is the key issue for reproduction of Japanese eels where identification and formulation of adequate sources of nutrition remain a problem.

For European eel, the research in reproduction will be continued in an EU-project “Reproduction of European Eel: Towards a Self-sustained Aquaculture Project acronym” (PRO-EEL) co-ordinated by J. Tomkiewicz, DTU Aqua: The project started 1 April 2010 and builds on the results of the Danish projects where the recent year’s intensive research and new technology has led to considerable progress

by improving methods for hormonal treatment, fertilisation and larval culture techniques. The larvae obtained in culture and reared for a maximum of 18 days resemble morphologically the earliest known larval stages from the Sargasso Sea.

7 Perspectives

The European eel population is at a historical low level. The recruitment of glass eels is in all areas below 10 % of that observed in 1970s and seems to continue to decline. All available information indicates that the mortality on wild eels is very high and most probably only a very small fraction of the glass eels entering European costs reach the silver eel stage and migrate back to the Sargasso Sea. To support the recovery of the European eel it is therefore essential that the mortality on wild eels is reduced substantially and ICES is recommending that **"**all anthropogenic impacts on production and escapement of eels should be reduced to as close to zero as possible until stock recovery is achieved"

The eel management plans, implemented in accordance with the EU framework regulation for the recovery of the stock of European eel, seek to reduce human impacts with a broad range of measures including reduction in fishing mortality and restorations of habitat. In addition to the measures related to fisheries and eel habitats, restocking is included in most eel management plans.

The time horizon for possible recovery is expected to be very long. Following ICES recommendation that anthropogenic impacts should be reduced as much as possible it is unlikely that fisheries on yellow and silver eels can form the basis for a sustainable harvesting of European eel in the recovery phase. The eel industries may therefore in the medium term most likely primarily have to rely on aquaculture of eels.

The aquaculture of eels is today limited by the availability and price of wild glass eels. The mortality of eels in aquaculture from glass eels to yellow eels is, pending on the fishing methods used when catching the glass eel, low compared to the mortality most wild eel populations suffers. The yield per recruit (glass eel) is therefore in general higher in aquaculture than in fisheries on wild eels and an eel industry relying on aquaculture of glass eels has a lower impact on the European eel stock than the same production being based on catches of wild yellow and silver eels.

However, in order to reduce the anthropogenic impacts to lowest possible level a sustainable aquaculture of European eels for human consumption will require that European eel can reproduce in captivity. Priority should therefore be given to research on reproduction of European eel.

Implementation of restocking plans included in many countries eel management plans relies in many cases on elvers produced in aquaculture on basis of wild glass eels. It is therefore essential for restocking that an aquaculture production of elvers is available.

Concern has been expressed that closure of aquaculture of European eels even for a short time period may jeopardize research in reproduction of eels and the implementation of the restocking plans included in many of the management plans adopted in Europe.

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DTU Aqua
Institut for Akvatiske Ressourcer
Danmarks Tekniske Universitet

Jægersborg Allé 1
2900 Charlottenlund
Tlf: 35 88 33 00
Fax: 35 88 33 33

www.aqua.dtu.dk