FIGURE 8
Restocking of glass eel and yellow eel juveniles in Europe

Source: Anonymous, 2006.

presents the series of glass eels or elvers introduced in the European waters from the mid-1940s to the present. Figures are lacking from France, Spain, Italy, Ireland, and Germany where some restocking programmes exist.

There are some major efforts among the countries involved in restocking. For example:

- In Belarus, from 1956–2002, more than 56 million eels were released into 44 water bodies covering a surface area of 48 500 hectares (Petukhov, 2002). Since 1988 no regular introductions have been made.
- In Poland, from 1951 to 1980, an average of 18.2 million eels was released annually into 559 lakes. These introductions, according to Leopold and Bninska (1983), had an important impact on eel harvests.
- In Lithuania, the first stocking operations took place between 1928 and 1939 when 3.2 million elvers were released into lakes of the Vilnius region (Shiao *et al.*, 2006). Since the mid-1960s, Lithuanian lakes have been stocked with 50 million yellow eel juveniles representing an annual average rate of 1.1 million eels (Lozys, 2002).
- In Sweden, the stocking of lakes is an old tradition, beginning as early as the eighteenth century. From 1976–1980 about 1.5 tonnes of elvers were imported from France and stocked along the coast and in lakes. Starting from 1979, the Swedish Board of Fisheries allocated SKR425 000 (approximately US$63 500) for annual restocking activities (Wickström, 1983).
- In Ireland, Moriarty (1983) detailed the release of 13.8 million elvers from 1960 to 1974 into Lough Neagh to increase production. The results suggest that at least a tenfold increase in catch elsewhere in Ireland could be achieved by expanding the existing restocking programme.
- In Denmark, a national stocking programme has been in place since 1987, financed through sport fishing licence fees. The seed are imported from southern Europe, pre-grown in local farms and released in brackish (75 percent) and fresh (25 percent) water bodies. In 2004, the programme was scaled down due to the poor harvests and the high price of glass eel (Pedersen, 2005).

TABLE 3
Variation in glass eels price from 1993–2006

Fishing seasons	93/94	94/95	95/96	96/97	97/98	98/99	99/00	00/01	01/02	02/03	03/04	04/05	05/06	06/07	Mean monthly prices (€)
15 to 30/09	137					221	168								175
01 to 15/10	137				305	221	152	226				485		540	254
16 to 31/10	137			198	168	274	183	290				490	655	540	299
01 to 15/11	137	168	168	198	122	244	152	373	320			540	640	560	278
16 to 30/11	137	137	160	213	114	320	107	389	320	351		590	680	510	293
01 to 15/12	122	114	145	229	114	366	183	450	198	330	380	720	665	560	309
16 to 31/12	91	84	122	274	114	238	204	343	252	309	365	670	450	350	271
01 to 15/01	76	84	137	335	114	198	274	290	274	210	345	660	450	390	265
16 to 31/01	61	76	168	412	114	152	183	285	308	210	350	670	400	400	261
01 to 15/02	61	69	137	229	152	171	226	305	198	235	315	820	380	490	254
16 to 30/02	61	76	137	305	198	118	175	290	149	230	430	950	480	670	277
01 to 15/03	76	91	137	229	305	111	130	213	202	250	570	1 100	390		293
16 to 31/03	84	91	152	252	503	107	177	267		235	750	1 020	400		336
01 to 15/04	91	99	152	274	274	114	192	309		255	640	970	380		313
16 to 30/04	99		160	229	305	113	201	351			540	900	360		326
01 to 15/05	114		168	152	305	113	233	320			520	930	430		329
16 to 31/05			168		290	133		290				930	450		377
01 to 15/06			175		290			290				800	470		405
16 to 30/06								274		220		750	485		432
01 to 15/07												700			700
Mean annual price (€)	101	99	152	252	223	189	184	309	247	262	364	773	563	501	

Source: Nielsen, T., personal communication, 2007.

In recent years the price of glass eel has increased significantly due to the growing Asian demand and due to a decrease in the glass eel production by half since 1995 (400–500 tonnes compared to the current 200 tonnes) (Tables 3 and 4). This situation allows the glass eel fishery to retain its profitability even at low harvest levels, but creates difficulties for eel growers and fishery managers in finding the seed for aquaculture and restocking activities. A rapid price increase during the 2004 season impacted the restocking programme in Europe (e.g. Denmark) and most probably the overall profitability of the aquaculture sector.

Fishing seasonality

In the main areas of glass eel distribution, i.e. the Atlantic coast from the south of the British Islands down to Morocco and in the Mediterranean, migration occurs during the whole year as observed by Charlon et Blanc (1982) in the Adour River in the south of France, by Antunes (2002) in the Minho River in the north of Portugal and Sobrino *et al.* (2005) in the Guadalquivir in the south of Spain. However, the main fishing season occurs during a more restricted period as defined by fishing regulations or by economical constraints, such as an insufficient density of juveniles in the estuary for fishing to be profitable.

Fishing periods differ according to the river basin district: November to March in Italy, with a peak in January (Ciccotti, 2002), and in the southern part of France (Prouzet *et al*., 2001). For the Adour River, the main fishing season shortened with the reduction in the eel resource (Prouzet, 2002). During the 1960s the length of the main fishing season was four months (from November to February). Currently the fishing season is no longer than two months, either November-December or December-January. On the Cantabrian coast of Spain, the main fishing season generally occurs between December and February (Garcia Flores, Herrero and de la Hoz Reguls, 2005).

In the southern part of the European Atlantic coast, the fishing season takes place earlier. For example, in the Guadalquivir estuary of Spain, the fishing season is between October and March of the following year, with peak fish densities between November and January (Sobrino *et al*., 2005). The fishing season is generally later in the north of France. For example, in the Loire River, the main fishing season is between January and March, as in the Vilaine estuary (Feunteun *et al*., 2002). In the Channel (Baie de Somme), the fishing season takes place between February and April, with March the best month (Rostiaux and Delpech, 2006).

In England and Wales, most of the glass eels are caught in the spring, but some pigmented elvers may be caught later in the season (Knights, 2002). In Ireland, glass eels are known to arrive off the Irish coast beginning in mid-December, but significant catch takes place in the estuaries from February to mid-April (Poole, 2002).

Handling procedures and equipment used for transportation

There is not a single standard procedure for handling European glass eels. As the methods of capture vary greatly from country to country (e.g. traps, dip nets, trawls), even from region to region, so do the ways of handling and transporting the fish. The commercial boats operating in French rivers are among the most representative way of handling the fry. The fishermen typically trawl for 5–25 minutes and deposit the catch on a plastic grid (mesh size 5 mm) on top of a holding tank (see Figure 6). The most active glass eels will immediately find their way through the grid while wounded and exhausted specimens will have to be helped with the aid of a brush. A variety of other small organisms such as shrimps, worms, fish, etc., find their way through the grid as well. Larger items are discarded overboard. The young eels are kept in the tank and the water is renewed, depending on the equipment onboard. After fishing the tanks are emptied into a fine net and the eel catch placed into buckets with a little water or into flat boxes if there is a substantial catch.

The eel catch is taken to a local collecting station, which is either a building situated along the river bank or a mobile station, e.g. a van with a tank and scale for weighing the catch. The eels are carefully drained of water, checked for bycatch and dead fish, and placed into the holding tank. A receipt is issued to the fisher, and once a week a payment invoice is issued based on the tickets collected, which are added up and multiplied by the "riverbank price", i.e. the price paid to the fisher. The price can vary from river to river, depending on the quality of the fish supplied, which often depends on the fishing method used.

After resting, the live eels are retrieved from the holding tank and transported to the wholesaler following the removal of dead fish and bycatch. The wholesaler may employ a team of riverbank collectors who receive a regular salary and a bonus for every kilogram of eels collected. Alternatively, the wholesaler may simply purchase the fish from autonomous collectors. Dead fish are usually sold separately.

After a further resting period of 24 hours, any dead and damaged fish or remaining bycatch (mainly shrimp, nereid worms, eel fingerlings and other species of small fish) are removed. Wounded glass eels, usually called "swimmers" or "whites" (as they turn milky in appearance) are removed by hand nets or skimmers as they are likely to die during transportation or when released into the farming tanks. The fish are kept in the wholesale facility for 2–4 days depending on their quality, market prices and transport availability. The temperature in such holding tanks can be controlled, which is important at the beginning and end of the fishing season when the water temperature may exceed 10 °C. The correct temperature limits weight loss and pigmentation, the market preferring transparent glass eels rather than dark ones. Once the eels have recovered from fishing stress they are ready to be delivered to buyers, who are European eel farmers or Asian importers. The latter are mainly in China, which imports over 90 percent of all glass eels shipped to Asia.

Europe

The eels are usually transported in trucks fitted with specialized holding tanks or packed dry in polystyrene boxes and delivered by air or road to the final destination. Transport can last up to 36 hours. As eel catches have decreased recently, small trucks are usually used, e.g. 3.5 to 12 tonnes, fitted with 1 to 4 insulated tanks to prevent temperature fluctuations. Eighty percent of the trucks use pure oxygen instead of compressed air in order to reduce transportation stress and water turbulence from aeration. The trucks are also equipped with oxygen and pressure monitoring alarm systems. The trucks transport from 150 to 900 kilogram of glass eels. Payment is issued once the fish are safely delivered to the farm.

China

European eels are sold to importers, who buy import licences from the relevant government authority. Once the eels arrive in China, they are sold to distributors who transport the fish to the provinces where the farms are located. Chinese farmers are not in a position to import the fish directly due to strict foreign exchange regulations and transportation and organizational constraints. Furthermore the import licences are mainly in the hands of few large companies. The eels are initially cooled, weighted and dry packed into specially designed boxes for shipping. Packing has reached a high degree of technical sophistication and a team of 3 persons can pack up to 500 kilograms/hour (Figure 9).

The boxes are transported to the airport in refrigerated trucks, and transferred to the airline companies who are generally well informed on the delicate nature of the goods. The plane cargo hold is usually maintained at +5 °C during the flight. Customs clearance in Asia is carried out as quickly as possible in order to shorten the overall transport time. The maximum transport time to ensure good eel survival is around 38 hours, with an average time of 26 hours. When the fish arrive in Asia they are delivered to an unpacking facility usually located within an hour drive from the airport. During unpacking, the seller's agent is usually present to report on quality. The typical guarantee in China is a maximum 3 percent loss and a maximum deviation of 5 percent in the number of glass eels/kg, as the Chinese importers sell the glass eels to the local farmers by piece. Following this inspection process the fish are repacked within 4–6 hours after reception and transported to the Chinese provinces that farm the eels, mainly Fujian, Jiangxi and Guandong. Fish shipped to China are paid in advance by the importers.

Reliable techniques have been developed for the transport of glass eels to the farms and only unpredictable accidents cause severe mortalities, e.g. truck accidents, flight problems. Over 95 percent of the shipped eels make it to their final destination alive. The weak link is the capture methods used

FIGURE 9
A box sample used for the transport of live glass eels to Asia (top) and a European eel delivery truck (bottom)

in some areas. Mortalities up to 45 percent can still be recorded in some rivers in the north of France compared to the 10 percent reported in the southwestern part of France or the 2–3 percent loss reported in England. The fishing sector needs to reduce mortalities throughout its capture operations.

AQUACULTURE DEPENDENCY ON THE WILD SEED

Wild versus hatchery produced seed

Eel aquaculture is 100 percent dependant on wild seed and the supply of glass eels is decreasing. Some harvest areas seem to be declining more rapidly than others, but, as the European eel population must be considered as a whole, the overall supply is at risk. The collected seed material in Europe exceeds the needs of the aquaculture industry, and the excess supply is consumed in Spain as an expensive seafood delicacy (Table 4). If artificial breeding of the European eels becomes possible, it could still take many years before the necessary quantity of seed required for farming becomes available and can be economically produced.

During the 2004/2005 season, purchases from Asia started late when the glass eel supply was no longer available in sufficient quantity to meet the demand. This caused prices to rapidly increase and peak to an unexpected level of €1 150/kg. At this price the European farmers could no longer buy any glass eels to stock their facilities, as they could only afford to pay €700/kg (approximately US$1 100/kg) and still remain profitable. If this situation had persisted for several seasons, European eel farming would have closed down.

The Asian eel farming industry is based on two species, i.e. *Anguilla anguilla* and *Anguilla japonica*. The local species is much preferred to the imported one especially in Japan as they perform better in terms of growth and survival rates. However, the supplies of *Anguilla japonica* had decreased considerably forcing eel farmers to find other supplies and the European eel began to be imported into Asia. The supplies of *Anguilla japonica* have started to increase again in recent years for unknown reasons, rising from the low catch of 15 tonnes in 2002 to over 100 tonnes in 2006.

Future of eel aquaculture

The European eel farming industry is stable and the production meets the current market demand. The industry however is not expanding; no new farms are being constructed, and the existing ones are in a reasonable to good economic situation.

The Chinese industry, on the other hand, has undergone a serious crisis over the last two years, as the intensive use of prohibited products, such as malachite green, was disclosed and all exports were banned from China to Europe, Japan, China Hong Kong Special Administrative Region (SAR), Republic of Korea and other Asian countries. Many eel farms had to cease operation as they no longer could sell their products. The import of European glass eels decreased in 2005–2006 and is likely to decrease even further (Table 4). The Asian eel market has suffered from this crisis as well, with customers being afraid of “potentially carcinogenic products” in the farmed eels. The Chinese eel farmers claim to have succeeded in raising eels without using such products. The market confidence will have to be bought back at high cost for the farmers, meaning that the Chinese eel farming industry is not likely to grow significantly in the coming 2–3 years. European glass eels, as long as they do not decrease further, will be able to supply aquaculture demand for at least the next 2–3 years.

If the Chinese eel farming industry had not faced this problem, the collection of European glass eels would not have been sufficient to meet demand. The Chinese importers would have turned their attention to the American species (*Anguilla rostrata*), and taken the available quantities there as well. Even with this new supply the shortage would not have been addressed and other eel species would have been tested.

TABLE 4
Glass eel harvest (in tonnes) and their use in aquaculture and direct human consumption

Fishing season	Total catches	Consumption in Europe	European aquaculture	Chinese aquaculture	China (% of total catches)
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	220	69
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	105	75
2001–2002	230	100	25	105	46
2002–2003	220	90	30	100	45
2003–2004	145	27	28	90	62
2004–2005	110	13	22	75	68
2005–2006	92	14	31	47	59

Source: Thomas Nielsen, personal communication, 2007.

Economic and technical implications of wild caught versus farmed seed

As there is no farmed seed available, comparison between wild and farmed seeds can only be estimated. If artificial reproduction of eels is achieved, it will still be questionable if the mass production can be realized and at what cost, compared to wild caught glass eels.

FISH FEED

Wild caught food

Eel farming in Europe relies entirely on wild-caught food: cod roe is used to wean the glass eels while artificial dry food, based on fishmeal and fish oil, is used for on-growing. In China, glass eels are weaned on cultured *Tubifex* worms for about one month, until they reach an average weight of one gram. They are then gradually adapted to an artificial pasty food for the rest of the farming process. Eels seem to be very sensitive to alternate protein sources and none of the tests conducted so far with non-animal protein sources have succeeded (Dana Feed, personal communication, 2007). Thus this species is still totally dependent on feed derived from wild-caught fish.

Cod roe – Most of this product is supplied by Danish fishmongers, who estimate the total quantity supplied to the eel farming industry at 20–40 tonnes per season. The cod (*Gadus morhua*) fishing industry easily supplies this quantity of roe and the price is less than €5/kg (approximately US$7.9/kg). The product is supplied in frozen blocks of 20 kilograms. If the cod quota drops in the future, and insufficient roe supplied, this feed source can be replaced with blended mussels which is available in large quantity. Initial natural food supply for glass eels is available without a problem.
Fish oil used in Europe – Although information is not available on the fish species from which the oil is extracted, the feed industry indicates that supplies are plentiful and not at risk over the next 10–15 years (Dana Feed/Provimi, personal communication, 2007).
Fishmeal used in Europe – As with fish oil, this source is apparently not at risk in the near future. The species used are exploited “at a sustainable level” (Dana Feed, personal communication, 2007).
Fish oil used in China – China imports fish oil from Chile, Iceland and the United States of America. One of the species used to produce the oil is the Pacific cod (Gadus macrocephalus). With an annual harvest of around 400 000 tonnes this oil supply can be considered steady and reliable.

Fishmeal used in China – Fishmeal imported in China originates from many countries, e.g. Chile, Russia, Singapore and the United States of America. The supply is plentiful and local feed plants do not expect any shortage, with various fish sources are used as raw material. As the eel farming industry has been profitable, eel farmers can afford higher feed prices than other fish farmers, assuring their access to feed supplies.

Artificial food

As the initial food used to wean the glass eels has a high water content (≈70 percent) it is important to rapidly switch over to a more nutritive food in order to obtain better growth. Artificial feeds for glass eels do exist, and tests have been conducted to compare efficiency of feeding and growth on eels started on natural food compared to eels directly fed with artificial food. The tests show that a higher percentage of elvers weaned on natural food start eating the artificial feed, resulting in better growth and survival rates. Use of natural food for on-growing is unsuitable for the farming techniques in both Europe and Asia. Even in Japan, where eel farming has the longest history, the natural food items used to grow eels (fresh fish, silk worm pupae, fish waste, etc.) have been entirely replaced by artificial feeds (Matsui, 1980).

The artificial food used in Europe is mainly extruded pellets, distributed via self feeders or automatic feeding machines. Feeding may also be completely automatic and managed by computer programmes. In Asia, most eel farms use a pasty feed prepared twice daily in kneading-machines. The paste is made available to the eels on floating frames or trays attached to the sides of the culture tanks.

Food resources

None of the feeds used to produce eels, apart from the cod roe, was previously used for human consumption.

Cod roe – The quality of roe sold to eel farmers is "pierced and damaged roe" plus "small roe" as large and whole roe is sold as a delicacy. The quality used for eel was previously sold to the canning industry or exported for production of *tarama* (a traditional appetizer – roe mixed with either bread crumbs or mashed potato with addition of lemon juice, vinegar and olive oil) in Mediterranean countries.
Fish oil used in Europe – This was previously used for other fish or animal feeds.
Fishmeal used in Europe – This was previously used for other fish or animal feeds.
Tubifex worms used in China – These were previously used for the aquarium food industry as both frozen or dried.
Fish oil used in China – This was previously used for other fish or animal feeds.

A significant increase of global eel production is not anticipated due to the limited supply of glass eels. Hence the supply of wild-caught feed is sufficient to meet the current eel farming demand.

ANTHROPOGENIC IMPACTS

Analysis of the recruitment trends in the northern part of the eel distribution area, and particularly in Sweden and in the Baltic area, show that recruitment and escape indicators started to decline well before the 1970s (Anonymous, 2002).

One of the major causes of declining populations is habitat fragmentation due to the construction of obstacles to eel migration. More than 25 000 dams were built worldwide in the twentieth century. In the European Union it is estimated that 60–65 percent of all rivers have some form of obstacle which restrict eel accessibility to the middle and upper reaches of the rivers. This effect has been experienced more severely in the peripheral zones of the eel distribution area, in particular in Scandinavia where hydroelectric facilities have been in place for many years. It is highly probable that these changes to the rivers had a catastrophic effect on the production of yellow and silver eel sub-adults. By the end of the 1940s this area alone experienced a marked reduction in small eels and a decreased in eel harvests in the Baltic a decade later.

In France, there has also been substantial disruption of rivers, including dams built near river mouths to prevent the tidal flow from moving upstream. These structures prevent glass eel from migrating upstream and increases the rate of exploitation of the fishery just underneath the dam, e.g. in the Vilaine estuary glass eel exploitation is >90 percent of the population (Anonymous, 2002).

The negative effect of these dams on eel production is exacerbated by water turbines that dramatically reduce the survival of silver eels during the downstream migration. Mortalities depend on the type of turbine used, the position of the water intake compared to the river axis, the presence of protective screens and hydrostatic pressure differences. The problem becomes particularly complicated when there are several hydroelectric power stations along the same river. Prignon, Micha and Gillet (1998) estimate that on the Meuse River direct mortality due to the migration through turbines was 34–45 percent for male eels and 40–63 percent for females. Dönni, Maier and Vicenti, (2001) also showed that the cumulative eel mortality after the passage through 13 hydroelectric power stations on the Rhine is 92.7 percent. Eel survival is directly linked to free migration upstream and downstream.

The decrease in wetlands also impacts eels. Agricultural developments to increase water extraction or diversion for irrigation have caused severe degradation of lower drainage basin wetlands. It is estimated that between 30–40 percent of the 268 million hectares of cultivated land in the world are irrigated from surface water. In France the irrigated agriculture areas in the Garonne, Charente and Dordogne catchments have increased five-fold, from 100 000 hectares in 1970 to 500 000 hectares in 2000, while on the Adour the area increased four-fold (Teyssier *et al.*, 2002; Prouzet, 2002, 2003a).

Development of agriculture on these wetlands has also been accompanied in the increase use of chlorobiphenyls, heavy metals, and organochlorinated pesticides which are easily accumulated in the fatty tissues of the eels. A study in Belgium showed that 80 percent of the eel samples examined exceeded the acceptable polychlorinated biphenyls (PCB) threshold of 75 µg/kg (Goemans and Belpaire, 2002). The impact of this contamination on the physiology of eel and, in particular, on its reproduction, remains undetermined.

The introduction of *Anguilla japonica* into the Mediterranean in the 1980s caused the appearance in Europe of the hematophagous nematode *Anguillicola crassus* (Peters and Hartmann, 1986). This nematode resides in the wall of the eel swim bladder and probably reduces its ability to ensure hydrostatic balance at the time of the migration towards the Sargasso Sea (Möller *et al.*, 1991). The parasite is now widespread in Europe, with rates of infection of 55 percent in the Adour River (Anonymous, 1998) and close to 100 percent in many countries (Kennedy and Fitch, 1990). Fishing mortality varies according to country and river basin. The quantity of bycatch during glass eel fishing depends mainly of the location of the fishery, with greater bycatch in the marine environment than in brackish or freshwater. Most fishing boats are equipped with a sorting device which allows the removal of unwanted organisms (Figure 10). This kind of simple equipment limits the impact on non-target species.

FIGURE 10
Typical eel bycatch from estuaries and coastal waters in Europe

SOCIAL AND ECONOMIC IMPACTS OF EEL FARMING

Social impacts

From fisherman to consumer

In France, approximately 1 300 professional fishers are directly involved in glass eel harvesting in marine and continental waters (Castelnaud *et al.*, 2005). A leisure fishery also exists, but the sale of the eels is forbidden. Illegal fishing is an important problem on some estuaries, e.g. the Gironde and Loire. Illegal catches are difficult to estimate, but could be of the same order as the legal catch on some rivers.

In England, the glass eel harvest requires a licence that costs £63 (approximately US$126) and in 2005 805 fishers held a licence (Pawson *et al.*, 2005). Fishing is only allowed using handheld dipnets. In Spain, around 682 fishers harvest glass eels in the Basque country (Diaz and Castellanos, 2005). These fishers are not considered professional, but are authorized to sell their catch. In Asturias, on the Nalon River, there are about 50 eel boats licences for boat fishing and between 150 and 200 fishing licences for land-based operations. On the Esva River, there is also a professional land-based fishery, but the number of fishers is not recorded (Garcia-Florez, Herrero and de la Hoz Reguls, 2005). Eel fishing exists also in the Guadalquivir (Sobrinho *et al.*, 2005) in Andalucia, but the fishing effort and the catch have not been quantified. On the Mediterranean coast, a small fishery also exists on the estuary of the Ebro River in Catalonia (Spain).

In Portugal, glass eel harvest was banned in 2000, except in the Minho River on the boarder between Spain and Portugal (Coimbra *et al.*, 2005). However, the activity still continues to some degree as "Portuguese glass eels" are often available on the market. In Italy the number of licences is difficult to assess because there is no central registration (Ciccotti, 2005). There are possibly around 10 companies fishing glass eels in marine waters.

In Morocco the eels are collected using large traps that stretch across the river. There are 200 to 300 fishers collecting glass eel, and the activity supports the livelihoods of at least double this number. The total quantity of eels collected per season is around 3 tonnes, but due to poor conditions and materials used, only 1/3 usually survive following collection. All the fish are exported despite a national regulation stipulating that 75 percent of the glass eel harvested in Morocco are to be farmed locally.

The total number of eel fishers in Europe is estimated to be between 3 000–3 500, mainly in France, United Kingdom and Spain. The European eel fishers sell their catch to middlemen, of which there are around 80–100. Wholesalers purchase the fish from the middlemen and then place glass eel batches of 80–500 kilograms on the market as buyers are not interested in batches <80 kilograms.

In order to deliver glass eels to the European farmers and to the Asian importers, the suppliers need to run a fleet of transport trucks, have skilled workers and funds to purchase the glass eels. Only larger companies are able to assemble these means. There are 8 wholesalers in Spain, 9 in France and 2 in the United Kingdom. Wholesalers employ between 2–15 persons, and are often family-based companies. Some companies only work with glass eels, while others also trade in all sorts of seafood. The glass eel fishery alone engages around 3 300–3 900 people, not including those working in the aquaculture sector.

There are approximately 50 eel farms in Europe (26 in the Netherlands, 8 in Denmark, 3 in Germany, 4 in Spain, 2 in the United Kingdom, 2 in Sweden and 2–3 in Eastern Europe) and around 1 000 farms in Asia raising the European eel. In Europe, most farms sell their product to eel traders, mainly from the Netherlands as the size of the eels (i.e. 130/150 g) best match the Dutch market. Smaller farms sell all or part of their production directly to customers, as live, fresh and gutted, or as smoked, and obtain a better price for their product. The traders buy several tonnes from the farmers, grade the fish, sell the larger ones to Denmark or Germany, and the rest is smoked for the Dutch customers and sold as whole smoked eels or filleted smoked eel.

In China, the domestic demand for the end product is growing but currently only a small fraction of the production is sold locally. Most eels are exported, with Japan importing almost 80 percent of the production. The eels are exported live, gutted and frozen or prepared as *kabayaki* in China-based processing plants. The eels shipped to Japan undergo a severe health and quality inspection for possible contaminants and prohibited products before being allowed to enter the country.

The eel fishers are nearly all men, usually assisted by their wives or other family members. In France, they need to hold a "Capacity Certificate", be 18 years old and have acquired at least 12 months work experience on board of a fishing boat. French glass eel fishers make a good living and generate almost 90 percent of their annual income. The eel wholesalers in France are mostly based in the Basque country where most of the eel are traditionally sold to Spain. The number of companies trading eel is decreasing as the market is very competitive and many small family-size companies are unable to cater for the Chinese market.

Aquaculture impact on the eel market

Until 1985, glass eels were either used for direct human consumption or for restocking programmes. Supplies were so plentiful that in the early twentieth century the eel fry were fed to poultry and used to produce glue. Whole train wagons of glass eels destined for Spain were typically loaded in Nantes, France, with 50 kilogram jute bags of eels. The main source of glass eels was France and the fish were caught and collected around the main estuaries of the Atlantic coast and transported by trucks to holding stations along the French/Spanish border. When conditions were favourable, the trucks were reloaded to deliver the fish to processing facilities mainly located in the village of Aginaga in Spain.

From 1985 to 1993, European eel farmers purchased about 10 percent of the glass eels collected without affecting the overall market price of the commodity. The average price during this period was €40/kg (approximately US$63/kg) although adverse climatic events and festivities such as Christmas, New Year and San Sebastian day affect the price of the glass eels. Only few people or suppliers were interested in the aquaculture market for glass eel and supplied the European farmers during this period.

In 1993 China started to purchase the European glass eel (*Anguilla anguilla*) because the supply of the local *Anguilla japonica* was insufficient and prices had risen considerably. From 1993 to 2006 the average price was €300/kg (approximately US$474), with peaks of €1 150/kg (approximately US$1 816). The European glass eel traders could no longer ignore the demand generated by the aquaculture sector which was ready to pay much higher prices. The cooked eel market could not afford such prices and was only supplied with poor quality eel or the dead eel.

In the early 1990s the overall eel market for human consumption became very weak, and many eel farms in Europe and Asia were forced to shut down. A further crisis occurred in the 1998/1999 season when large quantities of farmed Chinese eels, following the imports of 200 tonnes of glass eels in 1996, flooded the market causing the eel price to drop by 50 percent. This resulted in the closure of additional eel farms throughout the producing nations. In the 2003/2004 season the Chinese industry somewhat recovered due to the lack of both *Anguilla anguilla* and *Anguilla japonica*, and importers paid prices of up to €1 150/kilogram (approximately US$1 816) of glass eels.

Eel aquaculture has sustained a fishing industry that would probably have ceased to exist if it continued to be based only on the consumption market. With the pre-1985 prices of less than €40/kg (approximately US$63) and current quantities of approximately 150 tonnes per season, the glass eel fishery would not be economically viable. Price levels created by aquaculture demand maintain the fishery. The companies involved in the cooked eel industry have had to reduce their staff, or simply close down, while others started the production of glass eel *surimi* products.

The impact of farmed eels on wild-caught eels arises because Dutch traders pay a higher price for farmed eels than wild eels. The farmed eels are in fact more suitable for the smoking industry due to the higher fat content, standard sizes, year-round availability, regular supplies and do not have the typical “muddy” taste which is often the case in wild fish. Furthermore, wild eels are also more susceptible to stress, often damaged following fishing (tail damage, mouth damage, etc.) and may experience high mortalities during transportation, grading or storage.

Employment and skill issues

Eel farming has generated new employment opportunities in Europe, but on a limited scale, as the farming technology used does not require a large team of workers and technicians. In the European smoked fish processing sector the farmed eel replaced the wild eel and therefore no major employment changes occurred. On the other hand eel farming in Asia has created significant employment in both the farming and processing sectors (Figure 11).

The transition of the fishing industry to eel aquaculture did not much affect the fishers as the final market destination of the glass eels simply changed, with buyers mainly from the farms rather than the processing plants. However, the shortage of glass eels brought about the banning of non-professional harvesters (e.g. in France) and forced many out of the fishery.

With aquaculture now so critical to this industry, the quality of the glass eels harvested and a reduction of eel mortality is of utmost importance. In spite of this, only few of the French fishers have really made an effort to supply better quality fish to the riverbank middlemen. Most of them are only concerned by the quantity of fish collected, rather than quality. If there was a real price difference between dead and live fish, or even between good and bad quality, the fishers would quickly react to this. The laws regulating the fishery including the net size and boat engine permitted are not adequately enforced.

Economic issues

Market evolution

Eel fishers can be considered as the main beneficiaries of the development of eel aquaculture activity. Without this evolution, the glass eel fishery would have become uneconomical and would probably have ended. The fishery is in fact sustainable only if the price per kilogram of eel is higher than €200 (approximately US$316). As the price per kilogram increased considerably due to the demand from the aquaculture sector most of the estuarine and fluvial fishers are making a decent living. Out of the approximately 15 major wholesalers before aquaculture took over the market, 7 have completely stopped trading glass eel or do not exist any longer, 5 have lost market share, and 3 are performing well. Three new companies have started exclusively based on supplying the aquaculture market.

FIGURE 11
Workers in a *Kabayaki* factory gutting and preparing the eels

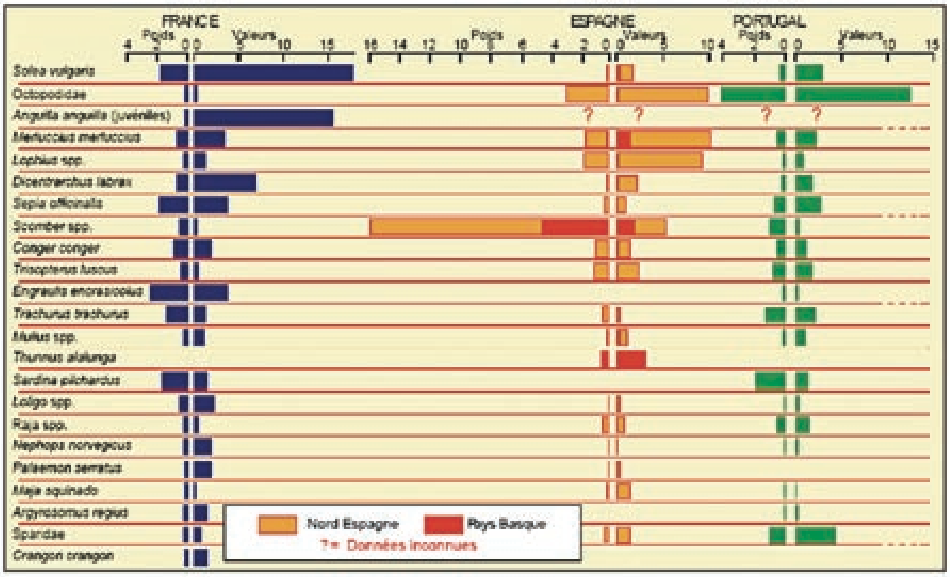
TABLE 5
Importance (in percent) of glass eels on the total turnover of the estuarine fishery on the Adour river from 1987 to 2000

	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Turnover (€1 000)	1 179	1 049	952	581.9	449.8	1 373	809.6	395.3	697.4	671.9	1 115	446.8	1 213	1 471
Glass eel	40.0	53.1	70.6	58.7	30.0	65.4	45.5	43.7	72.0	59.6	74.3	52.1	75.8	80.4
Migratory salmonids	27.3	26.9	7.2	16.1	21.4	11.8	15.3	18.5	7.3	4.9	4.9	11.5	7.2	6.8
Sea lamprey	14.8	1.3	6.2	9.5	19.1	14.2	23.2	2.8	2.9	10.1	12.7	22.0	7.4	6.8
Shad	7.6	7.0	5.3	4.8	14.4	2.4	3.9	15.2	6.3	9.8	3.5	7.0	6.2	3.9
Miscellaneous spp.[1]	10.3	11.7	10.7	10.9	15.1	6.2	12.1	19.8	11.5	15.6	4.6	7.4	3.4	2.1

Source: Prouzet *et al.,* 2001.

[1] Miscellaneous fish species include European seabass, yellow eel, Gilthead seabream, mullet.

FIGURE 12
Distribution of the main species caught by the small inshore fisheries along the Atlantic coast of continental Europe



Source: Leauté *et al.,* 2002.

Economic dependence of the small-scale fisheries

The eel fishing activity is conducted by different groups of fishers generally carrying out also other fishery-related activities such as oyster farming or sea fishing. Nevertheless, the small-scale glass eel fishery constitutes a major economic activity for most of the fishers involved as demonstrated by the Adour River (Table 5). On a larger scale, the EU project on the "Caractéristiques des petites pêches côtières et estuariennes de la côte atlantique du sud de l'Europe" (Pêches Côtières et Estuariennes du Sud de l'Europe – PECOSUDE) was undertaken to assess the economic impact of inshore and estuarine fisheries from the Loire estuary (France) all the way to the south of Portugal (Léauté, 2002). Among the 200 identified species or group of species landed along the investigated area, 7 species represented almost 53 percent of the total value in 1999. Of these, the European eel (especially the glass eel stage) ranked second in value along the French coast (Figure 12).

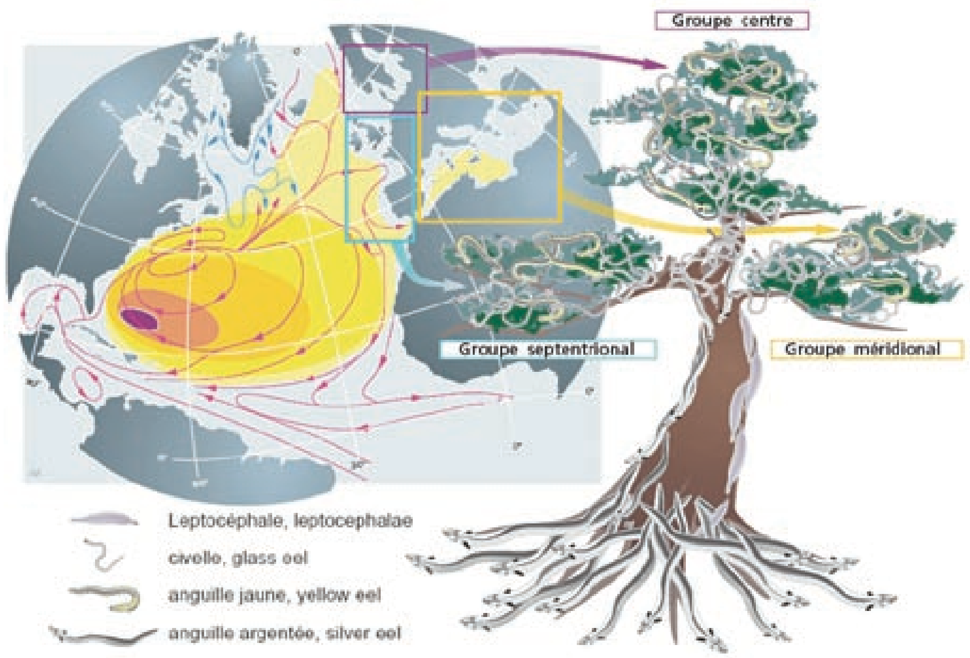
MANAGEMENT

Comparing the European eel population dynamics to a tree, its roots are in the Sargasso Sea, the rising and descending sap in the trunk and the main branches is represented by the North Atlantic circulation, which spread the leptocephali and glass eel to North Africa and European coast. The leaves represent the different catchments where elver, yellow and finally silver eel are produced and contribute to feed the spawning stock in the roots of the eel tree (Figure 13). This helps to understand that to have a real impact on the future eel population, it is necessary to manage the stock not only at the scale of the catchments, i.e. the management unit corresponding to one leave, but also to a larger scale corresponding to the canopy that represents the different areas of colonization. This scale and complexity of management is difficult to organize and requires coordination among all EU states exploiting the resource.

In order to manage and restore the eel population, which is considered as endangered and included in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), the Council of the European Union made a proposal for a Council Regulation establishing measures for recovery of the stock of European eel (13139/05 Pêche 203 – COM(2005) 472 final). This regulation would establish a framework for the protection and sustainable use of the stock of European eel of the species *Anguilla anguilla* in EC maritime waters and in the estuaries and rivers of Member States that flow into the seas in ICES areas III, IV, VI, VII, VIII and IX or into the Mediterranean and Black seas.

The plan proposes seasonal closures in order to reduce catch by 50 percent with an exemption allowed only if a long term management plan is established. This objective is defined as an escape to the sea of at least 40 percent of the biomass of adult eel relative to the best estimate of natural escape defined according to: historical data or by habitat-based assessment of potential eel production, in the absence of anthropogenic influences or with reference to the ecology and hydrography of similar river systems. The management plans may contain different measures, such as fishery regulations, restocking, improvement of river habitats, temporary switching off of hydroelectric power turbines, etc.

FIGURE 13
Functional scheme of the eel population: "The Eel Tree"



The eighth article is of particular interest: “if a Member State operates a fishery on glass eels, it has to guarantee that 60 percent of all glass eels caught during the whole year are utilized as part of a restocking program in European inland waters having access to the sea, for the purpose of increasing the escapement levels of adult silver eels. In order to ensure that 60 percent of glass eels caught are used in a restocking programme, Members States must establish an appropriate reporting system.”

That implies together with the reduction of the catch, a major decrease of the production of wild seed available for export to Asian countries. The evaluation of the efficiency of the management plans has to be assessed and for this reason a project called “Abundance and colonization indicators of European eel in the central part of its colonization area (INDICANG)” is being undertaken.

The diversity of the situations is such that each production unit should be considered separately. This approach was largely recommended by the scientific community, as it makes possible a systemic analysis. Fishing activity is not the only factor affecting eel populations. Other causes impact aquatic productivity, e.g. exploitation of the water for energy needs, exploitation of wetlands for urban and agricultural needs. Local scale efforts are insufficient because a restoration of the habitats and eel resource in only one catchment area cannot lead to a restoration of the resource on a European scale taking into account the diverse structure of the population. The implementation of a network of pilot catchment areas projects will allow a broader approach on a European scale, e.g. on a set of rivers between the Cornwall and the north of Portugal, as proposed in the INDICANG project (Prouzet, 2004).

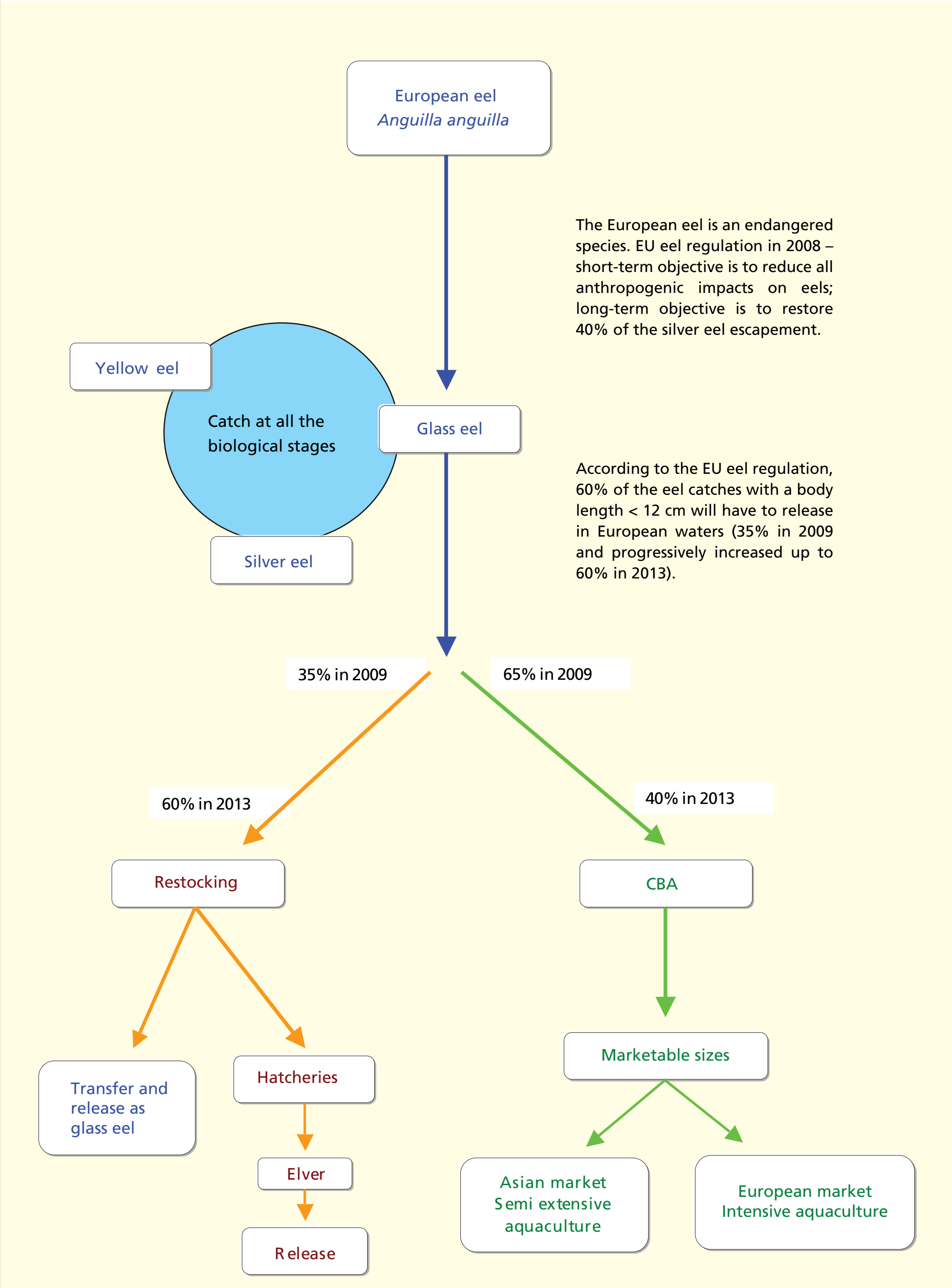
CONCLUSIONS

The biological cycle of the European eel is not yet replicated under artificial conditions, meaning that the removal of seed from the natural environment is still necessary to supply the aquaculture sector. This species is presently considered endangered and in order to manage and restore eel stocks, the EC is defining a regulation to establish measures for the recovery of its stocks (Figure 14).

Recent research indicates that the successful reproduction of the European eel will require a further decade for it to be carried out on a large scale, which means that eel farming will have to rely on wild-caught juveniles until then. Collection of glass eels will increasingly become uncertain, particularly if the eel population continues to decline at the present rate. In this case, the priority will be to ensure the natural colonization of glass eels migrating through the estuary of a given catchment area. If some catchments receive a surplus of natural recruitment a portion of the glass eels arrivals will be assigned to the stocking of rivers or lakes in Europe with insufficient recruitment. This stocking will be made either by the direct introduction of glass eels in rivers or by the release of elvers pre-grown in hatcheries. In both cases, strict sanitary controls would have to be enforced.

To implement this plan, the EU will have to fund the purchase of wild seed from fishers and elvers from eel farms. Government funding would ensure implementation of the plan and ultimately integrate eel production with natural recruitments to increase spawning stock in open waters. Fishing restrictions would protect these stocks. This also implies a transparency of the marketing networks. The European regulation proposes a decrease in glass eel harvest, and restrictions on the export outside the natural area of eel colonization. A restriction of 60 percent of the catch has been made (35 percent in 2009, to reach 60 percent in 2013). If this becomes law, it is highly probable that supplying glass eels from Europe to the Asian market will be greatly disrupted.

FIGURE 14
Functional scheme of the eel population: "The Eel Tree"



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