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A Review of Eel *Anguilla anguilla* Aquaculture in Europe : Perspectives for its Sustainability

Abstract

Eel farming cannot exist without getting wild young stages (glass-eels or elvers) coming from the sea. The eels grow quite slowly and require temperature higher than 18°C. For this reason, Italy was the main producer for a long time. This thermal requirement precluded eel farming from Northern Europe until efficient and cost-effective water circulating systems were developed by Denmark and the Netherlands and provided very intensive operations. In the last decade, EU eel aquaculture has increased from 5,300 to some 8,000 tons, representing a 50% increase. The main producing countries are now Denmark and the Netherlands. Some other farming also emerge in southern countries. Intra-EU market seems saturated (10, 000 - 11,000 t) and the whole flows mainly concerns live eels. However, the trade of eel combines aquacultured and wild eels and also different species, which is difficult to track to match a higher potential demand at European scale which is estimated at about 26-27,000 t. The development of Far East aquaculture and its boost in the late 1990 s precipitated considerable concern within the EU production sector for supplies of *Anguilla anguilla* glass eels. Indeed, all trends of eel recruits are declining and serious threats can be expected, which could impede a continuing profitability of aquaculture. Such a situation is discussed and we call for a new cooperation to associate all eel stakeholders worldwide.

Key words: European eel, *Anguilla anguilla*, Aquaculture, Europe, Sustainability

The European eel (*Anguilla anguilla* L., 1758) is distributed in most of Europe's coastal and inland waters, as well as in Northern Africa. Its extremely uniform genetics have suggested panmixia, and Schmidt's findings[1] suggest that eel spawning area is located in the Atlantic ocean (Sargasso Sea). Recent findings based on microsatellite DNA analyses[2,3] have suggested the possibility of genetic differences within the stock, but at present, the species is still considered as a panmictic marine species.

The eel has always been exploited, by widely scattered fisheries, in all aquatic environments such as coastal lagoons, estuaries, rivers and lakes, all over its wide distribution area. Most of the eel supply to the market comes from intensive eel culture, well established in Europe for more than 30 years. European eel aquaculture is today an important

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industry, amounting to about 11,500 t in 1999.

It is well known that the main limiting factor for eel aquaculture lies in seedlings, i.e., glass eels or elvers to start the production cycles, with particular regard to its availability, quality and price. Induced reproduction of this species is to be considered out of reach for the near future, despite the basic and applied research going on at present on the reproductive biology of eels[4-8] . Therefore, the link between eel aquaculture and wild eel stock will raise more and more questions, from both an ethical and a productive perspective.

A series of problems, in fact, such as the widespread recruitment decline all over the European coast and the adult catch contraction in many ecosystems, have been causing concern for the future of the European eel stock. The general picture on the status of eel stocks and fisheries throughout Europe displays declining recruitment and reduced yields, apparent both for capture fisheries and for scientific indices[9,10]. Oceanic factors at a global scale[11], heavy exploitation and environmental degradation have been considered responsible for the general decline in eel recruitment in addition to the shrinkage of eel stocks at a local scale. As a consequence, there is a debate going on and some actions being undertaken at international level, aimed at outlining a management strategy taking into account different, and apparently contradictory, aspects such as the maintenance of food supply and employment, maximization of production of natural resources, protection of the species and conservation of biodiversity. All this has resulted in advice for the resource management and in recommendations [10-12] that will constitute the basis for EU considerations. In 1997, the EU, having acknowledged that the eel stock is outside safe biological limits, requested AFCM and ICES to advise on the management of the European eel.

While AFCM drastically recommends a total closure of the eel fishery, ICES has suggested that a recovery plan should be prepared, reducing in the meantime the fishing mortality to the lowest possible level. The need *a)* to avoid collapse of the whole stock *b)* to maintain sustainable fisheries, by setting common stock-wide targets at EU level, has been reiterated, as well as the adoption of the Precautionary Approach[13-15] for the management of the species[16].

The main conservation target has been identified in the safeguarding of the spawner escapement, being the migration of silver eels from the continent the provider of oceanic spawning stock biomass. Measures to be undertaken are, therefore, the reduction in overall catches and the enhancement of local stocks by restocking and improvement of migratory routes for all migrants. Intra-watershed restocking seems a preferred option, to minimize the risks of transfer of diseases and parasites and in light of the new genetic findings[3].

The present paper presents a review of the eel culture situation in Europe, also from an evolutionary perspective, in order to highlight the links between the aquaculture sector in Europe and the wild stock situation, which is nested within a global scale market as expressed by Fontenelle *et al.*[17](this volume). This paper also points out some possible solutions towards a sustainable aquaculture, i.e. an aquaculture that takes into account some responsibilities for the conservation.

A brief history of eel aquaculture in Europe

Eel exploitation on a "culture" basis has a long standing tradition in the whole Mediterranean basin, in relation to coastal lagoon management in the whole area. This practice has always been based on the intercept of seasonal migrations of some euryhaline fish species (eel among them) between sea and brackish water areas: ascent of juveniles to lagoons, more suitable for growth, and return of adult fish to the sea for changing environmental conditions, primarily temperature, or reproduction. To exploit these periodic movements, large areas were enclosed, and permanent capture systems were consequently

developed and improved.

The first true "aquaculturists" were the Romans as demonstrated by the numerous ruins of fish ponds for the maintenance of live fish (the *murenarii*), but evidence of active hydraulic management of lagoons date back as far as the V-IV century B. C., with the Etruscans, in the central Tyrrhenian[18]. The eel became an important commercial species in Italy by the 1300s, when it was first extensively reared in the lagoon of Venice and in the whole upper Adriatic region, with the *vallicoltura*. The famous Comacchio *valli* reached a peak in prosperity in 1800 thanks to the eel and its processing industry. The *vallicoltura* differs from coastal lagoon management practiced in other similar environments by a more active running. This includes fry stocking, active hydraulic management and special fishing devices, the *lavorieri*, that is the traditional fish barrier based on the principle of V-shaped traps. In other coastal lagoons, such as the Sardinian ponds or the French ponds or the lagoons of north African countries, artisanal fisheries are also well developed, while management is simpler and mostly based on the natural fry ascent. Eel yields in coastal lagoon environments depend primarily on environmental quality, even more than on recruitment. Those two features both influence management operations with reference to fishing efforts and to restocking. Thus observed yields were extremely variable, from the 6 kg/ha observed in Comacchio in the mid '1980s[19], to the 300 kg/ha obtained in Monaci coastal lake in 1984 by means of restocking with small yellow eels[20].

Extensive culture played a major role in European eel production, namely in Italy, up to the 1970s, when the whole sector was struck down by a parasitic disease, "Argulosis", caused by the ectoparasite *Argulus giordanii*. This event, together with an increasing market demand, led to the first attempts towards an intensive eel farming, in open systems based on the on-growing in earthen or concrete ponds, following the Japanese technology already well established, and using either ground-waters or warm effluent waters. Limiting factors were seedlings weaning technologies and food conversion rates during the growing phase, together with the necessity of frequent grading operations. During the 1980s, advances in feed preparation technology and improvements of farming techniques (engineering and water treatment technology, disease management) enhanced the potential for successful farming, mostly in Italy but also in other southern European countries.

Eel culture in Northern European countries was precluded by the thermal requirements of eels higher than 20 °C for optimal growth[21], which is 2-3°C cooler than for Japanese eel[22]. Some attempts were carried out by using thermal effluents from conventional or nuclear power stations in France [23,24]. For the early 1980s, efficient heated recirculating systems were set up in the Netherlands and Denmark reaching a high degree of technology today[25]. Hence, European eel farming shifted towards higher productions, with improved farming performances and reduced impacts on the environment.

Eel farming technologies in Europe

On the whole, two different farming typologies are present today on the European scene.

The "southern Europe" technology still remains outdoors, as an open system on a more traditional basis, and is still widely practiced in Italy. But it has also spread to Greece, where eel farming seems to be expanding. Main features are earthen, or increasingly lined with concrete, tanks. In practice, the water temperature ranges between 8 - 28 °C with a water turnover of 2 - 5 l/s. The productive cycle lasts for 16-30 months depending on the starting seedlings (glass eels or small yellow), on densities comprised between 5 and 12 kg/m^3. The growth conversion factor usually ranges between 2.5-3:1. Total annual production depend on farm size and how the farm is managed: common ranges of 30-50 t can be noticed for small farms family managed, and of 100-400 t for industrial farms[26].

Another farming typology characterizes "northern Europe", which was developed more recently in Denmark[27,28]. This technology is based on indoor growing, because of heating, and the water is recirculated through sophisticated water treatment facilities including solids filtration, bacterial beds for conversion of ammonia into non-toxic derivatives, and ozonolysis. In such installations, tanks are usually in fiberglass or in reinforced concrete. All farming parameters remain relatively constant all year long, which results in enhanced farming performances. But, increased productions can be associated to better feed conversion, and increased densities. Actually, stocking densities are much higher, reaching 100 kg/m^3, thanks to the use of pure oxygen instead of aeration. Food conversion is much better (1.8 - 2.0 to 1 kg of eel produced in 1998) after improving the quality of feeds (high protein, > 50 % in the extruded adult grower feeds). Improved farming technology has significantly changed survival rates in eel farming. Common survival rates (from glass eel to final product) were reported as 20% in the 1980s and 50-60% in early 1990s, now reaching 80 %[27].

The success of these improved farming techniques led this technology to spread in the rest of Europe. Highly specialized companies provide the feasibility studies, and set up the recirculating systems as turnkey operations. These installations can be controlled by appropriate computers and alarm systems, providing total safety, which was not possible 10 years ago[27].

Seedlings production, i. e. glass eel weaning and first on-growing, has undoubtedly taken advantage of these advanced technologies by producing weaned elvers and small eels (5 - 20 g) with a good return. Some farms are specialized in producing only juvenile eels as a replacement for the wild glass eel. This tactics ensures a higher survival rate and a shorter farm period between purchase and sale. Among the other advantages, the recirculating technology is much more environment friendly whereas water settlement remains a problem in open systems. This is usually resolved with a sedimentation phase followed by "*lagunage* ponds", based on degradation of dissolved nutrients by bacteria and/or phyto-depuration. Another major issue lies in the required land area for this type of water treatment. For this reason, even in open systems, some farms have invested in recirculation units, at least for some stages of the productive cycle like the first phases of the on-growing.

Eel production in Europe

Related to the technology improvement, the eel farming production in Europe has displayed a steady growth over the last 20 years. The Aquaculture FAO statistics[29] from 1984 to 1999 (Figure 1), illustrates this feature, and a twofold increase during the last 10 years. This increase in eel aquaculture production seems to fill the gap created by the wild eel contracting yields, also shown in the FAO statistics, for the same period (Figure 1).

According to production data reported by FEAP (Federation of European Aquaculture Producers), which report total eel productions slightly higher than the FAO data (Table 1), eel farming appears to have stabilized in the last three years at around 11,000 tons[30]. However, all sources agree on the fact that main European producers are Italy, Denmark and the Netherlands (Figure 2).

Up to the mid 1990s, Italy was the leading country, with about 47 % of total European production. This country still accounts for the highest number of farms (over 100). At present, the Italian productive capacity and the market seem both to have reached a saturation at about 3.000 t/year (Figure 3). Nowadays, only a very small quota of the production (500 - 700 t) comes from the extensive culture in the Northern Adriatic (*valli*) and in other coastal lagoons. For this sector, the main limiting factors are the habitat changes related to coastal waters through eutrophication, pollution and seedlings availability for stocking. Indeed, "national" glass eels are more and more used for

restocking. The declining recruitment and the consequent shortage of glass eels supply cannot be compensated by imported seedlings on the one hand, and also because of higher prices, on the other hand. When we combine this with a rather long life cycle of eels in lagoons (7 years in average), which makes this eel as non-competitive compared with the aquaculture product, we can explain why other fish species are preferred when local management strategies are formulated[31].

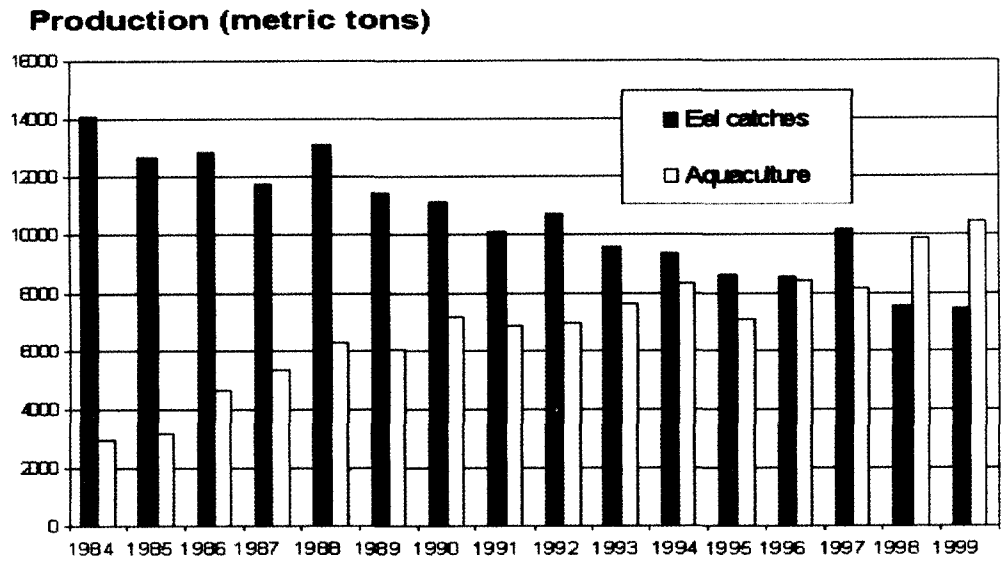

Fig. 1. European eel production by aquaculture and by fisheries in Europe (from FAO, 2001).

In the intensive sector, the Netherlands are now the leader country (Figure 4). In this country as in Denmark, the biggest investments have been made in the last decade. Production rose from 500 tons (1988) to over 5.000 for about 80 farms. If the average size of farms is variable, it must be noticed that at least two main farming firms, one in the Netherlands and the other one in Denmark, produce over 1,100 tons per year.

Eel farming is also reported for Spain, Portugal and Greece. The last two being new entries in the European eel culture scenario. With regard to Portugal, the FAO statistics[29] mention negligible aquaculture productions, but other sources[30] report production levels of about 200 t/year.

In 1988, the eel aquaculture in non-E. U. countries was still insubstantial. These countries used techniques we could define as extensive or very similar to managed fisheries. The only significant eel aquaculture activity can be now recorded in Tunisia, Macedonia and Morocco, with acumulated production estimated at 300 tons[29] .

Market, trade, consumption in Europe

The expansion of intensive culture in recent years led to a supply that seems to satisfy the existing market. In most cases, the cultured eel is preferred because of the reliability of supply and the possibility of ordering eels for a given size.

Seventy percent of the European market in 1992 was represented by Italy (35%), Germany (24%) and the Netherlands (11%). The main European target of the eel market remains Germany where the market capacity has

recently grown as a result of their unification in 1991[27]. Notwithstanding a doubled production, the whole consumption within Europe from 1988 to 1992 has remained exactly the same, from 26,240 tons to 26,244 tons[27]. This can be related to the other farmed species (seabass, seabream, salmon) which also compete on the market and can cover the increased demand for farmed fish.

Table 1. Aquaculture production of *Anguilla anguilla* in European countries from 1995 to 2000 depending on the marketed sizes (from FEAP, 2001).

PRODUCT	*COUNTRY*	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*
European Eels (unidentified)	BELG.-LUXBG.	150	150	150	150	30	
	DENMARK	1,200	1,200	1,700	2,468		
	FRANCE	180	160				
	GERMANY	600	140	150	150	150	150
	GREECE	234	350	312	500	500	600
	ITALY	3,000	3,000	3,100			
	NETHERLANDS	1,650	1,800	1,800	3,250	3,800	4,000
	NORWAY	200	200	200	200		
	PORTUGAL	200	200	200	200	200	200
	SPAIN	174	210	266			
European Eels Total		*7,588*	*7,410*	*7,878*	*6,918*	*4,680*	*4,950*
European Eels - 130/170 g	BELG.-LUXBG.						20
	DENMARK					285	250
	HUNGARY					7	8
	ITALY				1,200	1,200	1,200
	SPAIN				260	280	350
European Eels - 130/170 g Total					*1,460*	*1,772*	*1,828*
European Eels - >300 g	BELG.-LUXBG.						10
	DENMARK					2,415	2,250
	HUNGARY					12	13
	SPAIN				10	20	30
	SWEDEN	158	184	215	250	250	250
	TURKEY			200	200	200	200
European Eels - >300 g Total		*158*	*184*	*415*	*2,360*	*4,797*	*4,653*
European Eel Total		7,746	7,594	8,293	10,738	11,249	11,431

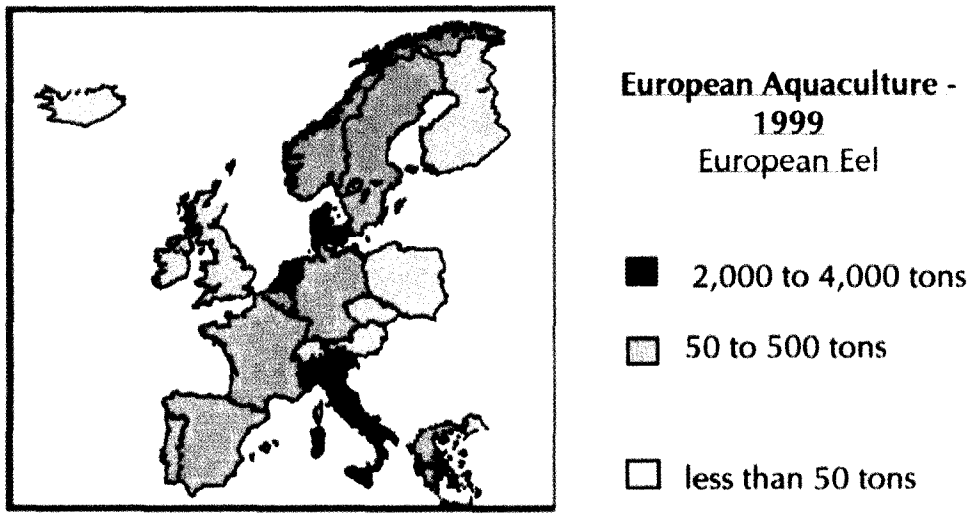

Fig. 2. Map of European countries involved in aquaculture of European eel in 1999 depending on their production level (from FEAP, 2001).

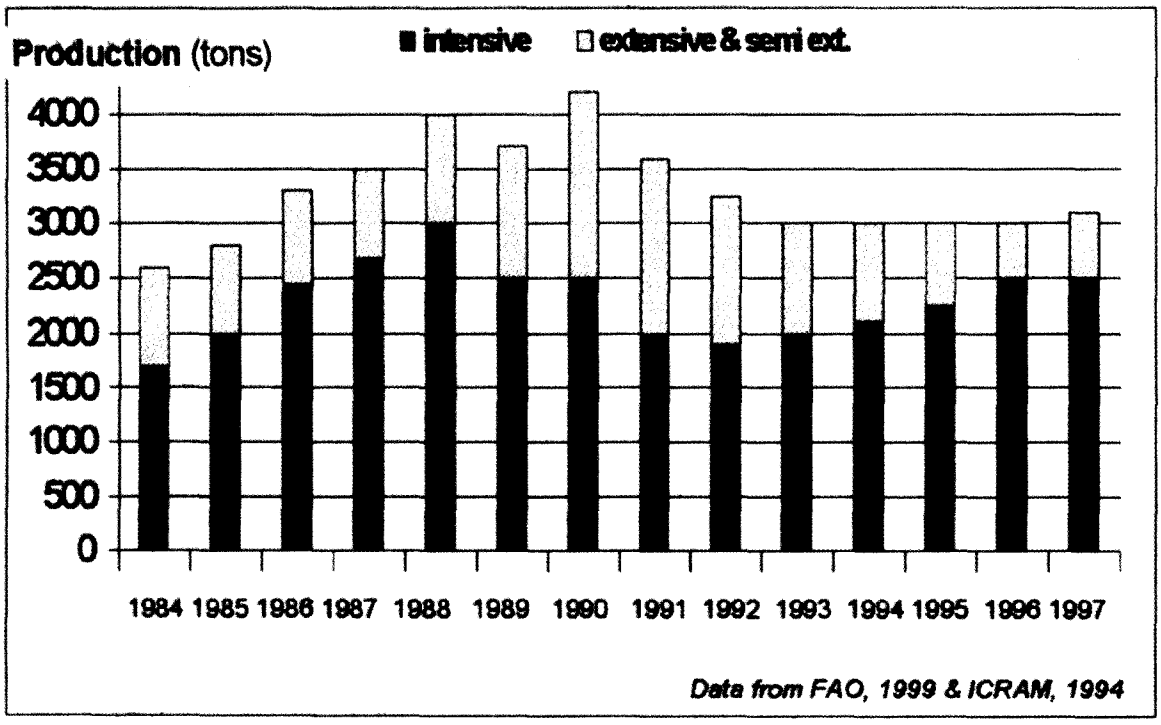

Fig. 3. Trend of aquaculture of European eel in Italy from 1984 to 1997 (from ICRAM, 1994 and FAO, 1999).

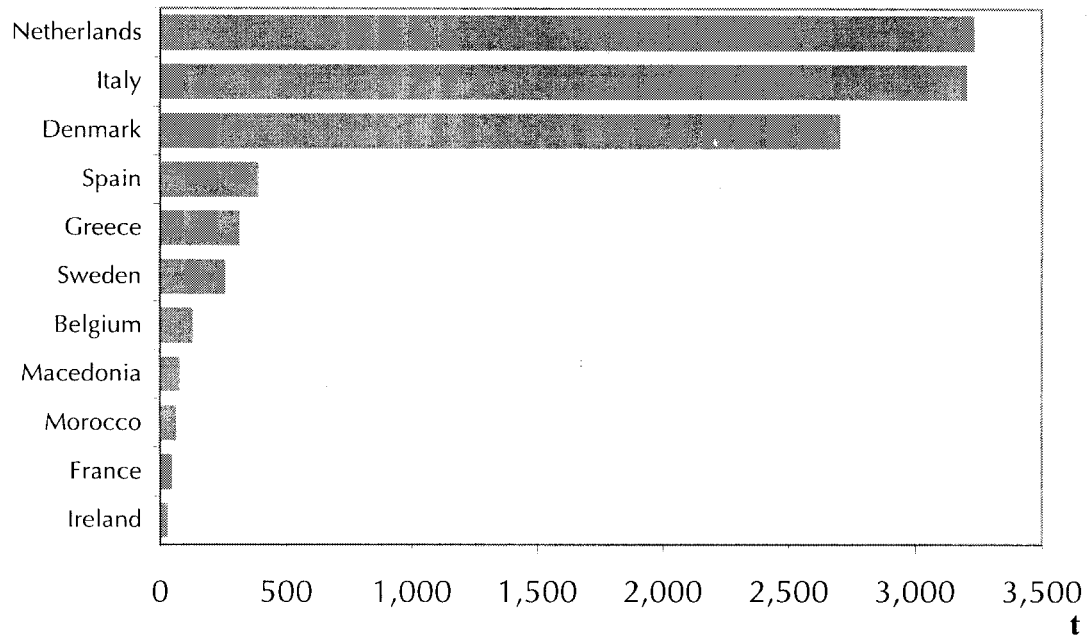

Fig. 4. Aquaculture production of *Anguilla anguilla* in European countries in 1999 (from FAO, 2001).

Market development has seldom received great attention with regard to the change of traditional and more recent demand combined with the relative scarcity which maintains high prices. Furthermore, the eel market can be considered a niche market when compared with other traditional aquaculture productions when we observe the eel consumption in some European countries: mostly Germany, the Netherlands but also Denmark for northern parts, and Italy in southern parts. The more recent productions, from Greece for example, are being traded within the European markets of Italy and Germany. Intra E.U. trading figures reported 10,000-11,000 tons/year for the period 1988-1992, while imports from non-E.U. countries was estimated at 5.000-5.500 t[27]. But, these trade data refer to wild and cultured eel, all aggregated; hence it is not possible to evaluate completely the trade of cultured eel. Although most farms, in both northern and southern Europe, trade only live eels, the processing sector is separated and subject to other types of investment.

In Italy, in the past, the marketed eels were traditionally separated into two sizes, since the time of *valliculture*. The same happens nowadays in the farming sector, and not only in Italy. Eels are graded at a suitable size of 140-170 g. These small eels, mostly males, are sold to particular markets (Italy and in The Netherlands, in the past), while females continue on-growing up to an average size of 500 g or bigger to be mainly sold for the German market all the year round and in Italy mostly during the Christmas festivities. The proportion of these two productions varies from one farm to another, which seems to be related to the environment and the fish density in tanks. Per capita consumption range between 0.2-0.3 kg per year within the main consumer countries. A similar level of consumption is also found in Belgium, while in all other countries the rates are much lower (0.08 kg per capita/year)[27].

The Italian consumption once exclusively oriented to fresh eel apart for a small quota of marinated eel as an expensive delicacy, is now slightly decreasing, with variations among regions and seasons. In Denmark, Netherlands and Germany, frozen

products also contribute to consumption. In Germany, perhaps the main consumer country in Europe today, the whole-smoked eel is also diffused, as well as diverse canned products.

In order to find new opportunities for an increased production, the processing of eel for kabayaki recently started in Europe, in particular in Denmark. Other countries also are getting interested in this Japanese way of preparing eels. However, this new venture faces higher costs, and difficulties to match the Japanese requirements because of the recent crisis in the Far East combined to the huge production of the continental Chinese farmers. This new type of production has been growing rapidly and induces a supply surplus to the current EU saturated eel market.

Limiting factors for European eel culture

Eel culture has been a profitable activity in Europe even if ups and downs for the last 10 years can be recorded. But the profits of this industry have reduced in the last three years. Production costs differ among countries, mostly depending on the culture systems. Furthermore, it is very difficult to evaluate profitability changes for the farming based on recirculating systems, since this is a relatively new development. However, we can admit that, within the last decade, the profitability has improved, or at least stabilized, when we observe the increasing number of farms using this technology. For outdoor farming, improvements come from an increased survival of glass eels/elvers due to improved nursery techniques, feed quality and better food conversion. But, both employment and financing costs have been increasing. Prices are usually fairly stable throughout Europe. On the contrary, the average European price has declined from € 10.5/kg in 1994 to € 7.35 in 1998. Depreciated imports and market stabilization have contributed to even lower prices in 1999, with a European average of € 6.22[27].

When we also consider that the European market demand seems saturated today, the implementing of new eel farms in Europe can be considered a main constraint. Instead, the main necessity should be to update the current technologies in order to decrease the production costs, to improve the quality of products, and to implement the treatment of effluents. Reducing most of the negative externalities related to the environmental aspects of this intensive farming should lead to turn this aquaculture into an ecologically sustainable industry.

We also think that further other questions should be raised by enlarging the scope of the eel industry. The European aquaculture cannot be disconnected from the global scene, in particular the Asian eel aquaculture developments, the European eel wild stocks as well as all the other eel species. All these aspects should be embedded in a new worldwide approach as suggested by Fontenelle *et al.*[17].

It has already been mentioned that the large and rapid increase in Chinese eel culture led to an outburst of production that induced repercussions on the European market, because exceeding supply led Europe to turn prices down. As a primary consequence, the growing Asian productive capacity increased the demand for glass eel from anywhere, and from Europe in particular, because of the current shortage of Japanese glass eels.

Up to the mid 1990s, notwithstanding the decline in recruitment, the dependence of European aquaculture on glass eel or elvers from the wild was not really considered a major problem. Indeed, the demand of glass eel for European aquaculture purposes was only estimated to about 40 t/year[12]. When the Far East aquaculture asked for more *Anguilla anguilla*, this upset the EU glass eel fishery scenario and markets. At a first stage (1997-1998), there was a sharp increase in seedlings prices within EU (more than 300 € / kg paid to fishers in France[32]. This new trend seriously alarmed producers, while a consequent increase in fishing effort on glass eels was observed by commercial fishers. Of course, this was also an incentive for poaching to get a premium from this new lucrative market. This picture seemed more dramatic when facing the continuing wide-spread

and prolonged recruitment decline already mentioned[12-17].

Chinese buyers can afford to offer significantly higher prices than European buyers (for both the aquaculture and consumption markets). Although all trade statistics are very difficult to get, official French exports of glass eels *Anguilla anguilla* to Asia (Hong-Kong and continental China) are reported to have risen from 80 tons in 1994-1995 to over 270 tons in 1997 [33]. The year 1997 looks a turning point for a major change in the world eel trade for the aquaculture industry searching for seedlings in terms of quantities and value (Figures 5 -6) which modified the usual flows among all countries involved in this trade. The shortage of available glass eels together with the bigger demand from European and Asian aquacultures leads to a very intensive competition.

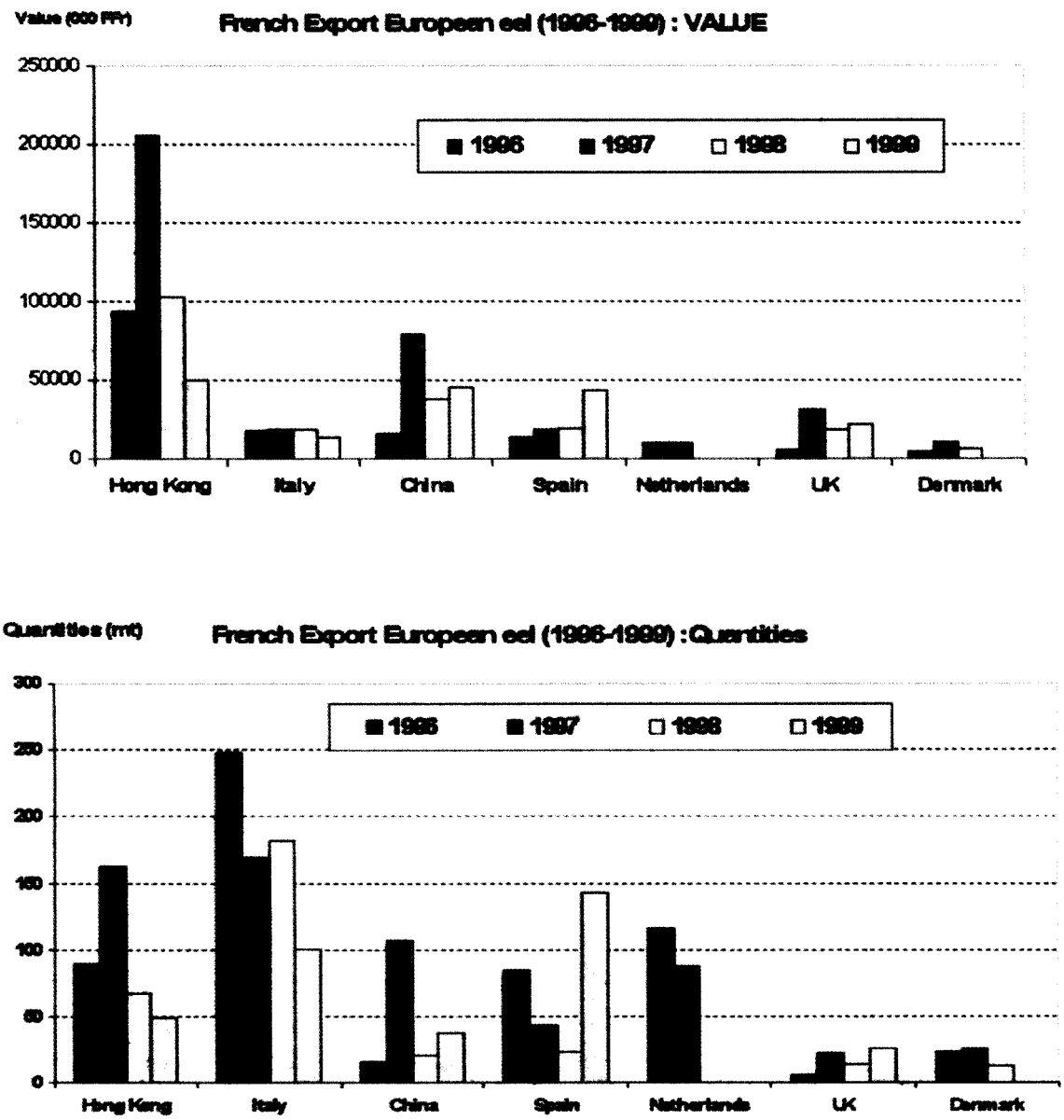

Fig. 5. Recent trends of French export of European eel in quantities and value from 1996 to 1999 (from FIOM, 1996-1999).

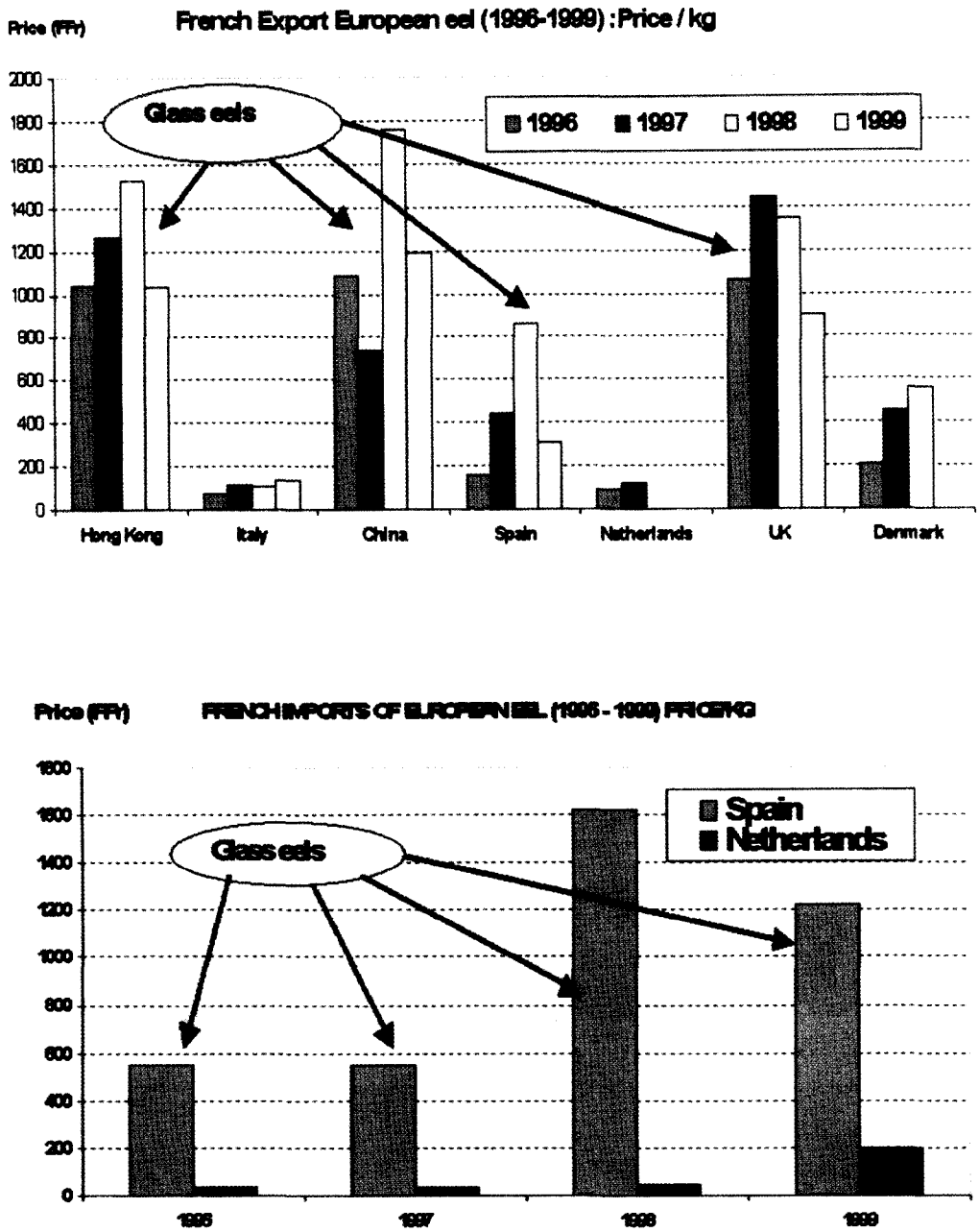

Fig. 6. Recent trends from 1996 to 1999 of price of European eel traded in French foreign exchange (from FIOM, 1996-1999).

Then, the production sector became more concerned to get an access for the glass eels at an affordable price. Glass eels of any *Anguilla* seem to be in the middle of a worldwide quest for providing all aquaculture industries with seedlings. Then, a double impact on the wild stock should be expected : (i) by an increased fishing effort on glass eels and (ii) a reduction of available stocks for enhancement. Restocking in open waters to sustain wild eel fisheries throughout Europe is often carried out by national fishery authorities; but higher price for glass eel reduced stocking practices everywhere, thus affecting

both local fisheries and local wild eel stocks.

Discussion

The overview given in the present paper allows a series of considerations on the present situation of eel aquaculture at a global scale, and some hypotheses with regard to its future.

From a general point of view, intensive culture has partly filled the gap created by the loss of wild catch. Indeed, it might have mitigated the pressure on wild stocks as the cultured eel seems generally preferred on the market because of reliable supplies and of homogeneity of quality and size.

On the other hand, eel aquaculture must explicitly acknowledge that it is entirely dependent on wild caught glass eels, and this can be interpreted as a strong negative externality: the transfer of wild glass eel to an eel farm has the same detrimental effect on spawning escapement as the direct consumption.

In Europe, until the 1990s, there was a balance between production and market, and glass eel withdrawal for aquaculture remained to sustainable levels. The new interactions with the Asian aquaculture and markets have completely changed the scenario, and a new balance has not been found yet. This unsustainable situation should be questioned seriously by all stakeholders.

Some constraints that have been mentioned for a further development of intensive eel production (market saturation, lower prices and higher production costs related to seedlings costs and technology updates) in Europe are probably true also for Asian eel culture. Decline of glass eel availability has proven to be a limiting factor in all Asian countries [35-37]. As a result, the Asian aquaculture now depends more on *Anguilla anguilla* recruitment. Whatever the causes of declines in recruitment and stocks of different *Anguilla* species may be, we are now all depending on very few wild species and/or on a few stocks within and beyond the bio-geographical distribution in order to sustain a huge industrial activity. Yet, the survival of this activity and the protection of the species must be combined as they are absolutely intertwined. The threat is now so obvious that the uncertainty about the European eel stock might lead to strict limiting measures by the E.U. Common Fisheries Policy in a near future.

In our opinion, eel aquaculture in Europe, in Asia and in other countries (India, Australia) should find a new dimension and new roles, within a framework of responsibility and sustainability, defining the new priorities which should be proposed and implemented at an international scale.

To become sustainable, any aquaculture must combine a profitable objective while minimizing adverse ecological change (local and global) as well as negative economic and social consequences, which could come from any activity connected to it. Thus, it will ensure the rational use of natural resources shared with other activities, and will be ecologically sustainable, respecting the integrity of land and ecosystems, while ensuring food and employment and economic benefits.

A responsible, positive, role for aquaculture ought to be identified within a sustainable management and conservation of the eel, in accordance with article 9 of the Code of Conduct for Responsible Fisheries[38], and in particular with point 9.3.5: "States should, where appropriate, promote research and, when feasible, the development of culture techniques for endangered species to protect, rehabilitate and enhance their stocks ... "

A starting point for a discussion on a possible role of a responsible aquaculture in eel management, should take into account three levels: the global scale, the regional scale and the local scale. Worldwide, some factors such as markets, competition for the resource, cooperation should be considered (Figures 7-8). At a regional scale, a possible role for recovery of traditional, extensive-based, patterns of production can be foreseen. Suitable environments are present in the whole Mediterranean basin, but also in other regions such as salt marshes on the Atlantic coast or enclosed fjords in northern Europe. These models, intermediate between aquaculture and culture-based

fisheries, fill in with the all the principles of a sustainable, integrated coastal area management[39]. It has been pointed out, with reference to the Italian situation[40,41], that extensive aquaculture models can play a fundamental role in the protection and safeguard of coastal lagoons and wetlands, because they guarantee the necessary basic management to preserve these environments. Recently Ciccotti et al.[31] have pointed out that a role can also be defined in relation to eel escapement targets.

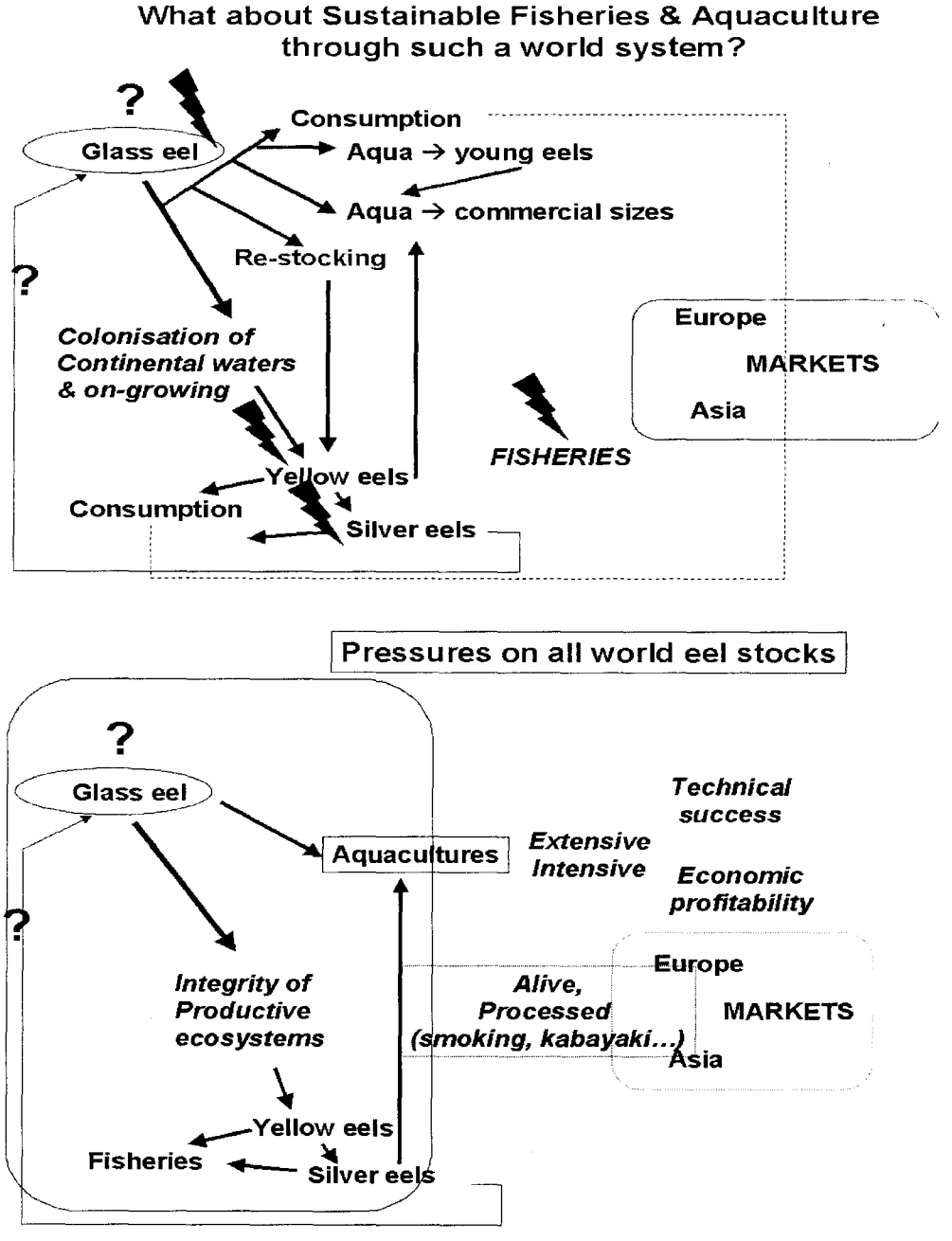

Fig. 7. Illustration of worldwide connecting flows among wild stocks, aquaculture and market for European eel.

Means the different threats on the natural life cycle due to increasing fishing effort and other causes which induce greater uncertainties of wild stock to match the higher demand for aquaculture and market worldwide.

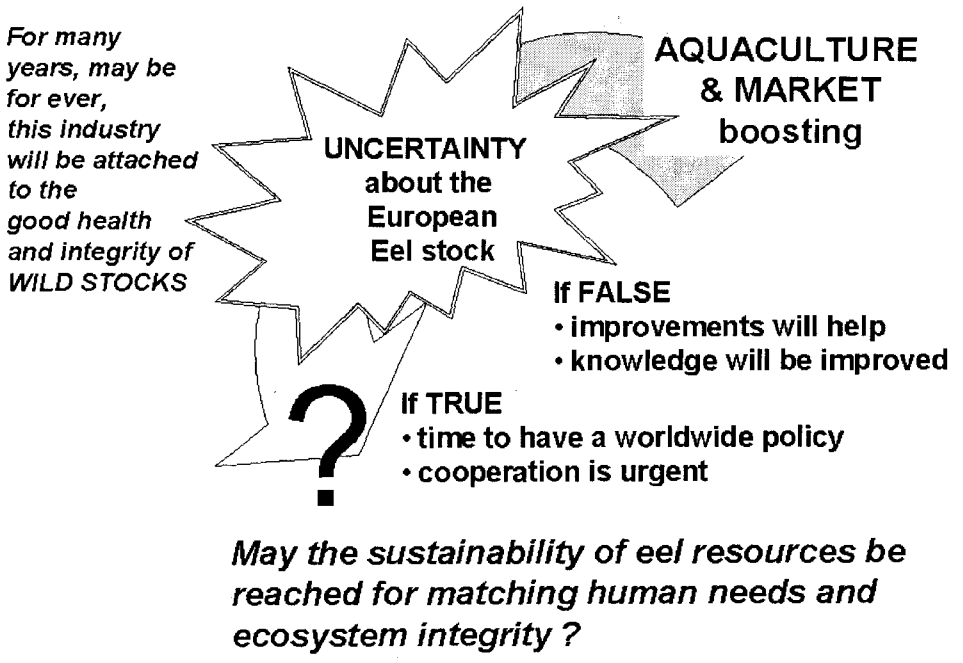

Fig. 8. Illustration of the current dilemma of aquaculture industry, all other users and managers to sustain European eel when so much uncertainty is existing.

As an example, silver eel production in lagoons has always prevailed. In the market, at least in Europe, without doubt there is an available "niche" for these productions whose quality is more similar to the wild, which could be certified. The fishery management of such sites could define suitable escapement targets of mature silver eels, so enhancing the contribution for the spawner escapees, and this also could be certified by eco-labeling[42,43]. Similarly, in some local sites, there might be room for a "restocking" product, i.e. seedlings suitable for restocking actions in open waters and obstructed water systems. The restoration of inland water stocks needs to be achieved through suitable restocking practices, actively involving professional fishermen and aquaculturists, with the implementation of locally-caught glass eels units yielding suitable seedlings. If restocking is considered acceptable only at the intra-watershed scale[9], and if success of stocking operations is not clear in terms of survival rates[12], this leaves room for small farming units to settle at watershed scale. Such small "nurseries" would be set up to preserve and/or restore endangered freshwater species and indigenous fish populations in rivers[44,45]. They would have to take care of glass eels from estuaries, enhancing their survival rate and first growth to the most appropriate stages for successful stocking in upper river courses.

The above mentioned options will not solve the problem of eel stock restoration or conservation, but they are hypotheses for the involvement of a responsible aquaculture in the management strategy at national and international level. They arise from a critical review of the European eel aquaculture and its relation with the wild stock. However, should this new strategy contain some elements worth to be exported to the Asian context? All countries must realize that neither one country, nor one region alone can solve the problem of a sustainable management of this peculiar resource, except by a collective cooperation and responsibility of all stakeholders.

If regulation is expected for fisheries and mainly for glass eels which are under pressure of aquaculture

buyers, aquaculture industry on a prorata basis should take a share in the efforts for restoring the wild stocks they depend on.

Some rules should be implemented like the customary Queen's gap within British estuaries where fish barriers for catching migratory fish let free a portion of the river for some fish to escape. The questions to address will become: how many escapees and who should monitor and evaluate this process?

Conclusion

In Europe as in Asia, the eel constitutes a very valuable species and its aquaculture has become a major component of production for a valuable foodstuff. The evolution of eel farming in Europe followed the same way as for most of the other fish species: fishing combined with management of water-bodies to keep young eels during their growth and to catch them later. Widely distributed in Europe for a very long time in coastal lagoons and freshwater ponds, this extensive step shifted to more intensive operations. Southern European countries used naturally warm waters while northern countries compensated this temperature issue by re-using warm effluent from power stations. However, the size of product was too small to allow any profitability of such ventures. In the 1980s, new technologies were developed in Denmark and the Netherlands, which boosted this aquaculture towards a very profitable operations as the market was highly demanding. This technology was also exported in many other countries like in Asia, the biggest market for the eel.

All things could have been nice if production and market had matched. In fact, this aquaculture presents all symptoms of a threat for its sustainability and a risk for the wild stock they will depend on for a long time. Indeed, we cannot dissociate this activity from the trends and availability of all natural stocks of *Anguilla sp.* As these stocks are declining in all countries, the successful aquaculture combined with the eel traders throughout the world should pay more attention to this threatening situation. Indeed, the current consumption market seems saturated within Europe and still expanding in Asia. Greater markets for "kabayaki" style seem expanding and lead to increase the aquaculture development. But, the seedlings to fill all aquaculture potential are not enough. This dilemma is a real challenge for all stakeholders. In addition to the international management of all natural stocks of eels which seems on the way, mainly in Europe, other ways should be proposed. Among others, we suggest that the aquaculture industry would feedback the natural potential of all watersheds by providing a share for on-growing to increase the potential outmigration of spawners, some years later. Embedded within a wordwide system, the sustainability of the aquaculture industry will be more and more linked to the integrity of the ecosystems capable to produce eels. It should constitute one demonstration of a possible win-win game by re-connecting a very sophisticated industry with the natural components it depends on. Let us hope this could be reachable.

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