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Criteria for cost-effective diversification for European finfish mariculture

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SUMMARY – European marine fish farming focused on the couple seabream and seabass. Species diversification is sustained by a better adaptation to local environments, to rearing techniques recently developed and to the new market trends, but also by an increase in rearing performance. Seabream and seabass have been chosen taking into account a limited number of parameters. The performance in both species of growth rate, fillet yield or adaptation to the processing industry requirements, for example, remain limited compared to those observed in some "new species". A selection work for "new finfish" candidates for aquaculture has been recently carried out in France. Cod was selected as the first candidate for aquacultural development on the western coasts of France (Atlantic, Channel and North Sea coasts). Halibut, wreckfish, dentex, pagrus or tuna might add value to other geographical zones.

Key words: Fish, "new species", selection, criteria, cod, gadoids.

RESUME – *"Critères de choix pour une diversification rentable de l'aquaculture des poissons marins en Europe". L'aquaculture marine européenne s'est concentrée sur la daurade royale et le bar. La diversification permet une meilleure adaptation aux conditions de l'environnement, aux nouvelles techniques d'élevage et tendances du marché mais aussi des performances supérieures en élevage. La daurade royale et le bar ont été choisis en prenant en compte un nombre limité de paramètres. Quelques performances relevées chez ces deux espèces telles que la vitesse de croissance, le rendement en filet ou l'adaptation aux demandes de l'industrie de la transformation demeurent limitées comparées à celles relevées chez quelques "nouvelles espèces". Un travail de sélection de nouvelles espèces candidates à l'aquaculture a été récemment réalisé en France. La morue a été sélectionnée comme meilleur candidat au développement de l'aquaculture sur les côtes ouest de France (Atlantique, Manche et côtes de la Mer du Nord). Le flétan, le cernier, le denté, le pagre ou le thon pourraient valoriser d'autres zones géographiques.*

Mots-clés: *Poisson, nouvelles espèces, sélection, critères, morue, gadidés.*

Introduction

European marine fish farming focused on the couple seabream and seabass for which the production respectively reached 70,000 t and 48,000 t in 2000. In 1998, FAO listed 44 marine fish species reared in the world (FAO, 2000) and 25 species were investigated in the Mediterranean area (Marino *et al*., 2000). This trend of diversifying the number of reared species is sustained by many reasons:

(i) A better adaptation to local environments: as most of the animal species, fish are poikilotherm species, their body temperature being close to that of external medium. Consequently, fish rearing performances are highly dependent on water temperature (Bœuf, 1988). That is why rearing costs may vary on regional localisation (Paquotte, 1992). Marine fish species presently reared in Europe are well adapted to warm temperature. This partially explains the development of their aquaculture in southern countries such as Greece. However, these species are not adapted to the very different environmental conditions met in Europe and especially in northern countries. The availability of a larger panel of "new species" will offer to the aquaculturists the possibility to select a finfish better adapted to their own environmental conditions.

(ii) An increase in rearing performances: compared to presently reared species, some "new fish species" present very high growth performances. Such capacity is a key feature for the development of a profitable aquaculture. Genetic modification of farmed fish will allow similar performances: for

instance, the first transgenic animal on North American dinner plates could be a salmon, growing more than 400% faster than a wild salmon (Anonymous, 2001a). However, many consumer organizations worry about the possible human health and environmental impact issues of GMO (MacLean and Laight, 2000). "Selected new species" may present high performances in captivity and especially a very high growth rate (weight of one year old fish, seabass: 0.1 kg, tuna: 5 to 10 kg) without using such controversial technology. This induces a right image, required for the development of new products (Mariojouls and Coleou, 2000).

(iii) A better adaptation to the wide range of rearing techniques recently developed: as listed by Blancheton *et al*. (1996), recirculating systems offer a good answer to the main requirements of today's aquaculture. However, fish density is increased from a maximum of 70 kg/m^3 in flow through systems up to 140 kg/m^3 in recycling systems (Blancheton, 2000). "New fish species" have to tolerate the very high densities maintained in these systems. On the other hand, large off-shore cages were also developed for pelagic species such as tuna which needs rearing volume ranging from 10,000 up to 200,000 m^3 (Caill-Milly *et al*., 2001).

(iv) A better adaptation to the new market trends: the standard fish consumer population just looking for fish flesh at low cost and ready to cook is increasing. Even in Italy where fish is well known, only 34% of the families could be considered as connoisseurs (Corbari, 1996). Between 1993 and 1999, the part of cuts of fish increased of 28% in value on the French market of fresh fish (Fig. 1). This trend is confirmed by the fantastic success of catfish and tilapia on the US market (Harvey, 1999). Since 1992, the US consumption of tilapia has been multiplied by a factor of ten (Anonymous, 2001b). The success story of farmed salmon, representing today close to one million tonnes, can be explained by the good image of this species, by its low selling price but also by its ability to be diversified horizontally (the same fish presented in different ways: whole, fillet, frozen, smoked, etc.) and vertically (a hierarchy of quality according to the geographical origin and process) (Mariojouls and Paquotte, 2001). The converging world-wide evolution of markets in developed countries due to free trade and to evolution of lifestyles, suggests the same situation is to be expected in other countries. As a consequence, new candidates for aquaculture must fulfil specific requirements given by these new trends and follow the specific characteristics of these "stars species" of aquaculture. After an initial "honeymoon" with a high profitability, market saturation lowered selling prices of reared fish species (Muir and Young, 1998). The selling price of seabass was reduced from 12 euro/kg in 1988 to 5 euro/kg in 2000 (Bjorndal, unpublished result). This decreased the profit made in this species. A few enterprises try to maintain a high profit by rearing new species. This is a short-term strategy because the fish selling price and the profitability will be decreased as soon as the production takes off.

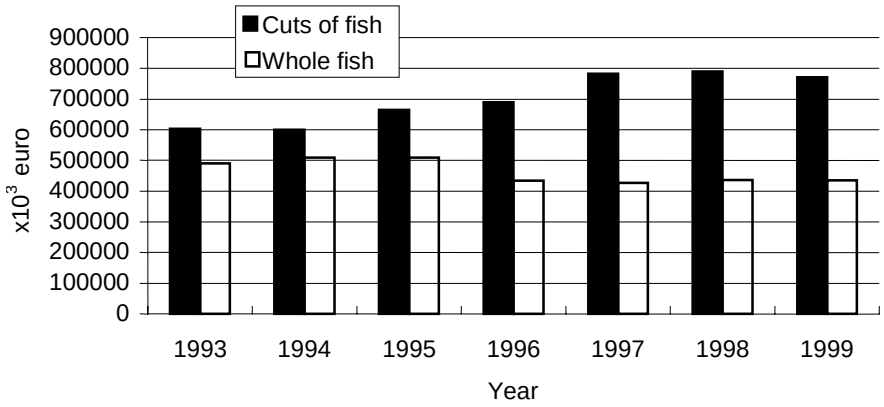

Fig. 1. Changes in the cuts of fish and whole fish French market shares between 1993 and 1999 (source: Secodip, 1993-1999).

(v) A better adaptation to the requirements of the transformation and distribution channels: except in Italy and in the Netherlands where traditional outlets are still dominant, supermarkets are now the first distribution channel for fresh seafood in Europe (from 45% of the share in 1980 to 70% in 1996; Paquotte, 1998). In France, the share of fish products distributed via super and hypermarkets increased from 21% in 1980 up to 65% in 1996 (Bjorndal *et al*., 1992; Paquotte, 1998). The

requirements of this distribution channel turn on supply regularity but also on the availability of a range of products and species and an homogeneity of characteristics for each type of product.

(vi) A disease risk diversification: in 1995, a serious outbreak of nodavirus was observed in seabass Mediterranean production: in 10 g to 600 g seabass, mortalities ranged from 15 up to 60%. Worldwide, 18 fish species were affected by nodavirus. However, the disease has not been observed in seabream even if they were reared in close proximity to affected seabass (Sweetman *et al*., 1996). As a consequence, a part of seabass production was switched to sea bream, highlighting that widening the number of cultured species contributes to reduce the risk of disease break (Basurco and Abellan, 1999).

From 1989 to 1997, the number of reared fish species has largely increased. However, it decreased in 1998, suggesting that some candidate species were forsaken (Fig. 2). Because market of presently reared marine fish species can be saturated, EU will promote research carried out in "new species" (Anonymous, 2001c). Through the FAIR and QOL programmes financed by EU, research were conducted in Arctic charr, common dentex, halibut and pike perch (Dos Santos, 2001). In China, rearing performances have been tested in 51 marine fish species belonging to 23 families (Hong and Zhang, 2001). Because a sustainable production sector for a "new species" may require 3 up to 10 years of research work (Muir and Young, 1998), such a strategy is time consuming. This fact sustains a careful selection of new candidates for aquaculture development. However, a global investigation, integrating a panel of parameters covering biological and economical scopes, has never been carried out in order to select these "new marine fish species". This paper aims at specifying the parameters useful for a cost-effective diversification for European finfish mariculture.

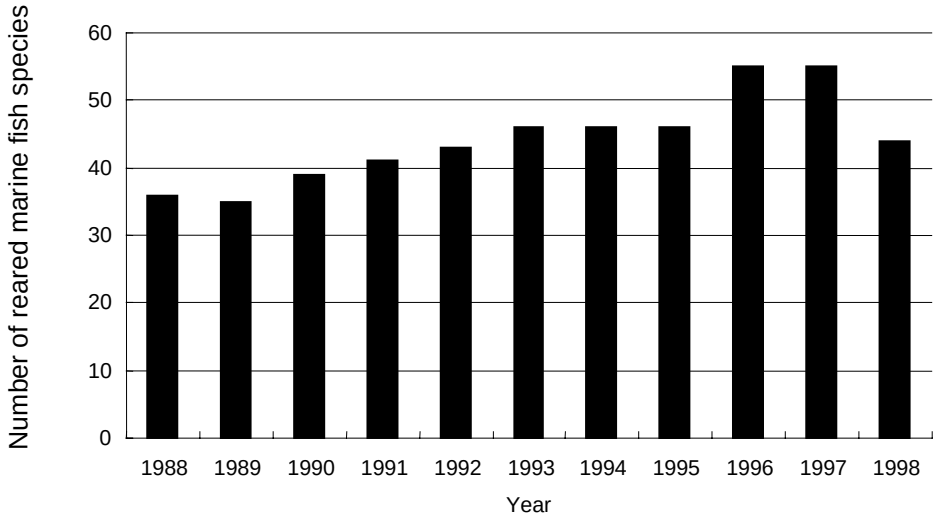

Fig. 2. Changes in the number of reared fish species (source: FAO, 2000).

The past: A choice rather than a selection

Seabream and seabass have been chosen taking into account their high selling price, their good reputation and the availability of juveniles or breeders in the wild. Such a choice is rapid and simple, and has resulted in the production of more than 100,000 t in the Mediterranean area. However, it takes into consideration a limited number of parameters, forgetting some essential aspects. For instance, the growth performances of seabass and seabream remain limited compared to those observed in some "new species" candidate to aquaculture (Fig. 3).

Because of processing, a high fillet yield is specially required. Compared to "new fish species", seabass, seabream and turbot present an intermediate fillet yield (Fig. 4).

Because of their low maximum size, seabass and seabream are badly adapted to the processing industry requirements: an inquiry conducted with the 13 main companies of the French industry

revealed the best characteristics of fish for processing: length = 0.5-1 m, weight = more than 1 kg (Méro, 1999).

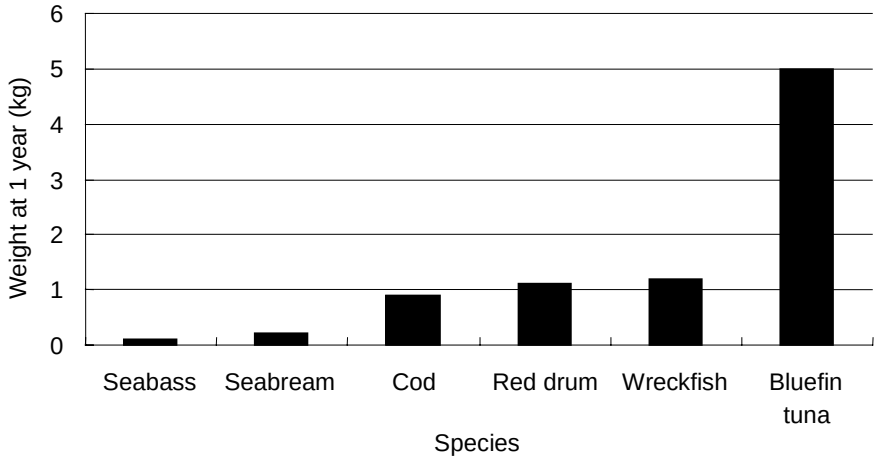

Fig. 3. Comparison of growth performances recorded in some traditionally reared fish species and "new fish species" (from Kentouri *et al.*, 1995; Quéméner *et al.*, 1999; Caill Milly *et al.*, 2001).

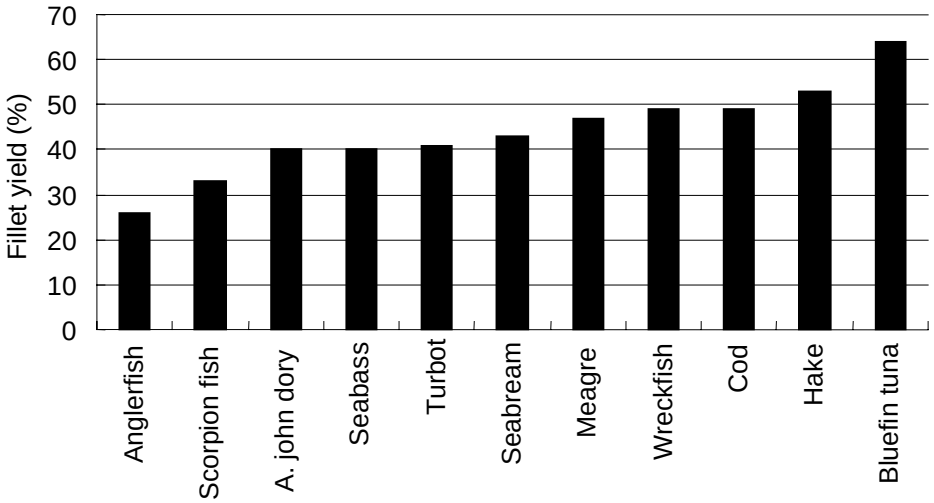

Fig. 4. Filet yield of some marine fish species (source: Furic Marée and Charlie Guennec Company).

These three parameters (growth performance, fillet yield and maximum size) suggest that the presently reared species were not the best candidates for aquaculture development. They were chosen without integrating their rearing potential, their adaptation to environmental constraints and the emerging trends of the seafood market.

First species selection trial was carried out by Fan Lee in about 500 BC. Criteria used by Fan Lee are still topical parameters: tasty and hardy species, not cannibalistic, low rearing cost and high growing out potential (cited in Mann, 1984). Today, few works have been carried out on the selection of "new species" candidate to aquaculture. The scope of these studies remains limited because they are:

(i) Restricted to a checklist of a huge number of questions covering scopes such as rearing performances, legal requirements and processing capacity (Avault, 1993).

(ii) Restricted to the analysis of the current control level recorded in successive rearing phases (Barbato and Corbari, 1995; Benetti *et al*., 1998).

(iii) Restricted to a low number of selection criteria such as the compatibility of targeted species with rearing conditions or the identification of suitable markets (Davis *et al.*, 1998). Other criteria such as a fast growth, an herbivorous diet, the possibility to obtain juveniles in great quantities and a great tolerance to environmental factors were suggested by Alvares-Lajonchere (1983). A bioeconomic index has been proposed by Mathews and Samuel (1992). But, it only considered growth performances and mean selling price of fish species.

(iv) Designed for very specific operating modes such as smallholder aquaculture (Brummet, 1996).

(v) Limited to a low number of candidate species (Benetti *et al*., 1998).

(vi) Limited to an *a posteriori* confirmation of targeted species (Suquet *et al*., 2000).

(vii) Presenting a panel of criteria without practical validation (Parfouru *et al*., 1997).

The studies conducted by Menu (1987) and Lensi (1995) used a combination of biological and economical criteria. However, they considered a limited number of previously targeted fish species. Furthermore, data were not expressed as mathematical values or notes which could improve their subsequent management. Jones (1972) proposed five criteria (market price, growth rate, food conversion rate, fish supply and production rate per m^2). He also presented an economical study, showing production costs and profits but in only 10 species targeted as the most valuable species of white fish caught around the British Isles. Selection works rarely use data collected in other fields such as fisheries or biology of wild populations. Most often they do not outline a predictive view. Except for Jones (1972: theoretical net returns) or Mathews and Samuel (1992: bioeconomic index) these works do not propose original criteria integrating several parameters.

Today: A sustainable selection of species candidate to aquaculture

In order to propose a sustainable selection of fish species candidate to aquaculture, inquiries were conducted in France in 1996 and 1997 (Anonymous, 1999; Méro, 1999; Thomas, 2000). They specified the requirements of marine fish farmers, of transformation (13 companies selected among the most important in France) and distribution (11 companies representing 80% of the national turnover) channels but also of consumers. Inquiries showed that 88% of the main groups of the French distribution channel were interested in the rearing of "new fish species". They also precised optimal characteristics of the new products required by these channels: a high body size adapted to processing, an absence of bones, a frank flesh colour, a high content of proteins, a large number of available presentation methods (fresh, salted, smoked, canned, frozen, etc.), a light taste and odour and a low selling price. This results recorded from both channels confirmed the emerging trends of the seafood market sector.

Cod was elected as the "star species" by transformation and distribution channels. Furthermore, the first six species elected by the transformation channel and the first three species selected by the distribution channel belong to Gadoids (Fig. 5).

Taking into account inquiry results, a selection work of new finfish candidates for aquaculture has been recently carried out in France. A panel of 34 criteria, considering biological but also fisheries and economical aspects, was used, integrating classical parameters: growth rate, selling price, availability of the breeders, etc. but also original ones: biological knowledge (number of publications in ASFA base), rearing potential (selling price/age at 3 kg: because this weight is the optimal one for processing, the denominator represents the duration of the production cycle), body section, presence of bones, presentation methods, flesh taste, reputation and geographic recovery (specifying the recovery rate between the geographic distribution of the species and the coasts of France). Data were mainly extracted from FishBase (1998), including information in 20,000 species. Furthermore, some supplementary information were communicated by aquaculturists, fishermen and fishmongers. Criteria, data and their weighting coefficients established for four profiles (aquaculture, transformation, distribution and consumption) were managed using a multiple criteria decision making method, Electre

III, used for agricultural planning (Roy and Bouissou, 1993). The result of the first geographical case (the Atlantic, the Channel and the North Sea coasts of France) showed that cod was the first candidate for aquacultural development on the western coasts of France. The candidature of this species is sustained by a high growth rate recorded in captivity, a good quality flesh, a high adaptation to processing machines, a good knowledge of its biology, the possibility to catch juveniles and breeders in the wild, the existence of successful rearing experiences and a very good image. Furthermore, the drastic decline of cod catches (Anonymous, 2001c) sustains the need of aquaculture. This selection work also confirmed the high interest of different species belonging to Gadoids (hake, ling and pollack) for aquaculture.

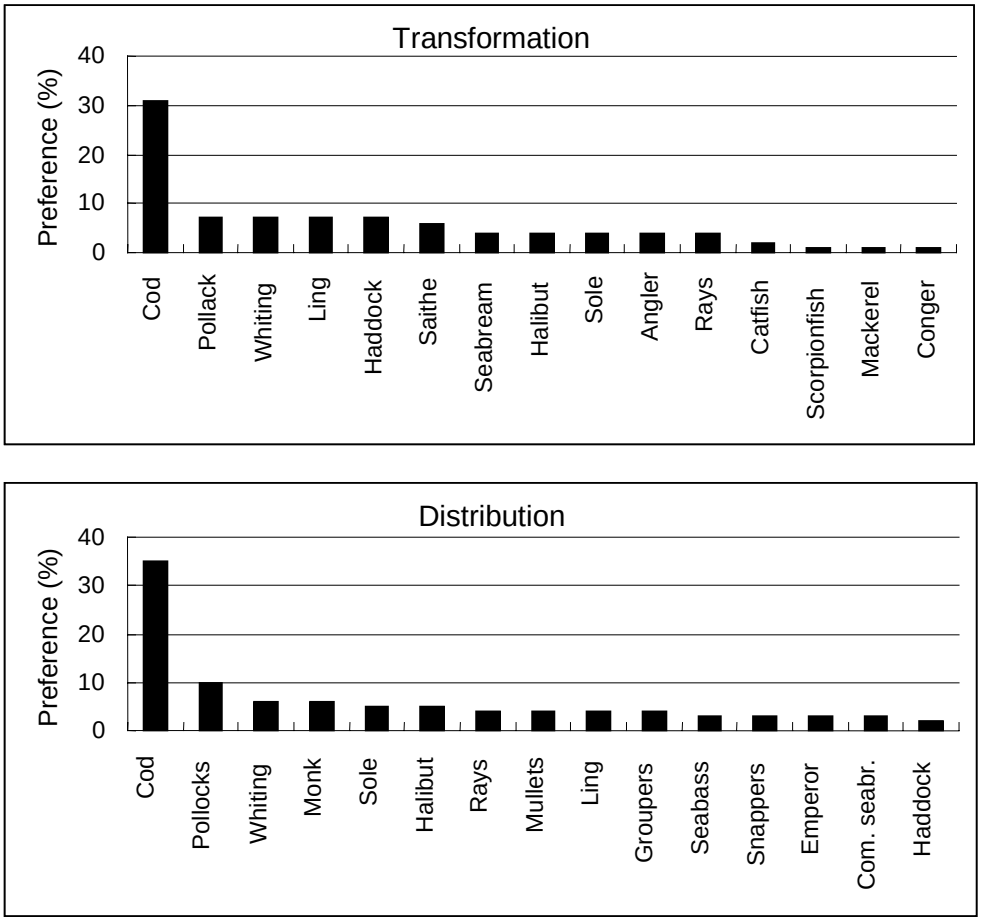

Fig. 5. Species preferences of the French transformation and distribution channels (source: Méro, 1999).

A few data were not available in databases: although parameter such as geographic recovery partially includes this information, the optimal temperature for rearing selected candidates was not precisely stated in some species. Such data must be specified using published works. In particular, the optimal temperature for cod growth depends on fish weight, ranging from 17°C for 2 g fish to 7°C for 2000 g fish (Bjornsson *et al.*, 2001). This corresponds to sea water temperature of the northern part of the west coasts of France.

Fish are highly dependant on environmental conditions. Among these factors and because most of these species are poikilotherm, fish are very sensitive to temperature changes (Table 1). The thermal preferendum is a species specific feature.

Like for other agro-systems of production, cost effectiveness and sustainability of diversification in fish mariculture will tend to a specific zonation and a geographical specialization, based on the better matching of environmental supply to biological constraints. The main criteria of this geographical specialization will be:

(i) The latitude which supports the thermal dependence into north and south (i.e. hot and cold water) species and provides conditions for matching specific thermal preferendum for reproduction or growth. This general zonation will be completed by the presence of permanent or seasonal up welling which provide micro thermal environments. As juveniles tend to present higher optimum temperature for growth than adults (Jobling, 1996), changes in thermal optimum according to the age of animals will create micro specializations in geographical zones, condition for segmentation of production between hatchery, pregrowing and ongrowing. Then, when the technology of exploiting deep waters for rearing will be available through under water cages or deep pumping, the influence of latitude will be reduced as temperature is more stable in deep than in superficial waters.

(ii) The distance from the coast which changes the quality of water, the pollution rate and the impact of terrestrial influence. This was not decisive with actual euryhaline fish. But this will probably be important for pelagic fish such as tuna which are sensitive to rapid changes in salinity or turbidity (Doumenge, 1999), but also amberjack, dentex or pagrus which are sensitive to microparasites and pathogens. Furthermore, this geographical situation will allow a better fuelling of fast grower species with high oxygen requirement: oxygen consumption of bluefin tuna is 2 to 5 fold higher compared to level recorded in salmonids and up to 50 fold higher than that of turbot (Bœuf and de la Pomélie, unpublished results).

Table 1. Optimum temperatures recorded for the growth of juveniles of some "new fish species"

Species	Temperature optimum (°C)	Reference
Wolffish	6	Lundamo *et al.*, 2000
Atlantic cod	11-15	Pedersen and Jobling, 1989
Halibut	12-15	Jonassen *et al.*, 1999
Pollack	16	Parfouru, 1996
Wreckfish	16-19	Tsimenides *et al.*, 2001
Pagrus	16-20	Divanach, unpublished result
Greater amberjack	16-22	Id.
Dentex	18-22	Id.
Striped mullet	18-20	Quéméner, unpublished result
Blackspot seabream	19	Martinez-Tapia *et al.*, 2000
Bluefin tuna	22-24	Caill-Milly *et al.*, 2001
Grouper	23	Divanach, unpublished result

A probable geographical specialization is proposed for some "new fish species" in Fig. 6. Rearing zones will preferentially be restricted to the south part of the distribution area of each species.

Some *post*-selection criteria must also be considered. Malformations of reared fish affect their conformity with wild standards but also their production costs (Divanach *et al.*, 1996). Compared to fish presenting no deformity, a 63% reduced growth rate was observed after 70 days in sea bass (initial weight: 1.5 g) affected by deformities of both operculi. Furthermore, conversion rates were 1.8 in normal fish and comprised between 2.5 and 3 for fish affected by deformities of one or two operculi (Chatain and Suquet, unpublished results). The lack of functional swimbladder in seabass and seabream juveniles resulted in a 20-30% smaller weight and a reduced survey by any kind of stress such as weaning, handling or hypoxic conditions (Chatain, 1990). Abnormalities observed in the past in cultured species are now reported in "new species": a high incidence of jaw malformation was reported in cultured striped trumpeter (Cobcroft *et al.*, 2001) as well as malformations of the swimbladder and vertebrae (Trotter *et al.*, 2001). In red porgy, changes in skin colour from orange-red of wild fish to dark silver affect the sales of reared fish (Kentouri *et al.*, 1995). As a result, abnormalities have still important implications for production management and the profitability of the enterprise. That is why criteria of good quality product such as morphometric proportions of fish larvae have been proposed to evaluate the quality of reared populations (Koumoundouros *et al.*, 1995).

In conclusion, "new species" could offer new opportunities to further aquaculture development. The recent outburst observed for cod in Norway where production could reach 30,000 t in 10 years,

sustains the strategic role of these "new species". This new start has to take into account the following three successive levels: (i) the history of aquaculture made of knowledge and techniques but also problems which form the experience of this domain; (ii) the selection process of new candidates which allows a good and sustainable start in the rearing of these species; and (iii) the new demand emerging from the society which will create a positive image, essential to the development of a new activity.

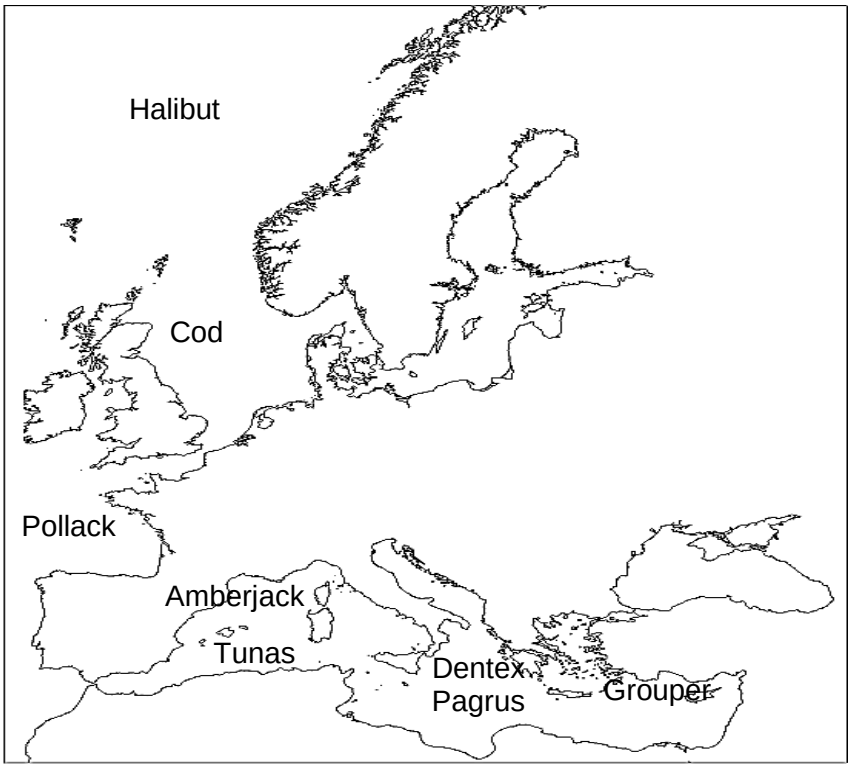

Fig. 6. Distribution of the rearing zones of some "new fish species".

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