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# The potential of brown trout (*Salmo trutta* L.) for mariculture in temperate waters

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## SUMMARY

The aquaculture potential of brown trout in marine waters has been investigated since 1984 trough a joint program from IFREMER and INRA. The results are described.

The species expressed surprisingly good performance under the environmental conditions of coastal France, characterized by elevated water temperatures (9–18°C) and salinities (34–35‰). Brown trout showed a high sea water tolerance, allowing a direct transfer in December as sub-yearlings, when weight exceeded 60 g. The case of extra NaCl in the diet allows to reduce the critical size at transfer and minimize the mortality. The growth was found to be identical to that of Atlantic salmon of Norwegian strain and better than that of local French strains.

The different populations tested experienced a high variability for fresh water/sea water growth as well as for the age at first maturity. Techniques for producing all female and triploidy monosex populations with heat shock methods, developed for rainbow trout, were successfully adapted to brown trout, and the performance of sterile female stock was found to be comparable to that of control diploids.

The specific nutritional requirements of brown trout are under inspection, the preliminary results indicating a higher protein demand than that of other species, particularly rainbow trout.

The effect of maintaining brown trout in sea water until spawning have been omened, showing a delayed ovulation and a decline in egg survival. Brown trout appears to be an interesting opportunity for French marine aquaculture, allowing to produce 1.5 kg fish over year after sea water transfer, and 3.5 kg after 8 months when using all female stock.

Key words: aquaculture, brown trout, growth, mariculture, *Salmo trutta*.

## RÉSUMÉ

*L'intérêt de la truite commune* (Salmo trutta *L.) dans le cadre de l'aquaculture marine en eaux tempérées*

La truite commune, à l'origine représentée uniquement en Europe, est maintenant présente sur tous les continents, sous la forme de populations sédentaires ou migratrices, à la suite de nombreux transferts et acclimatations. L'intérêt économique de l'espèce est vu exclusivement sous l'angle de la pêche récréative et les techniques piscicoles sont le plus souvent limitées à l'obtention de juvéniles destinés à l'ensemencement de parcours de pêche. Le potentiel de l'espèce pour la production de poissons de chair, destinés à la consommation humaine n'a pas été développé, principalement du fait de performances de croissance inférieures à la truite arc-en-ciel pendant la phase dulçaquicole. L'intérêt de cette espèce pour l'élevage en mer a été pressenti en France au début des années 1980, par la mise en évidence d'une forte croissance et d'une survie élevée en milieu marin. Il a suscité le développement d'un important programme de recherche commun à l'IFREMER et l'INRA, destiné à apprécier le potentiel aquacole de l'espèce et à en développer ses possibilités. Le présent document présente une revue des travaux menés et des résutats obtenus dans les domaines de l'élevage des juvéniles, des capacités de transfert et d'élevage en mer et de la reproduction. Les résultats plus spécifiques des programmes de nutrition et de génétique sont présentés dans deux papiers complémentaires.

Mots clés: aquaculture, eau de mer, *Salmo trutta,* truite fario.

## YFIRLIT

*Möguleikar á urriðaeldi í sjó*

Möguleikar á eldi urriða í sjó hefur verið rannsakað í samvinnu IFREMER og INRA í Frakklandi síðan 1984. Niðurstöðurnar eru kynntar í þessari grein.

Urriðinn reyndist miklu betur en ráð var fyrir gert við þá seltu (3,4–3,5%) og hita (9–18°C) sem er einkennandi í sjónum við strendur Frakklands. Urriðinn þoldi vel sjóinn þannig að hægt var að flytja hann beint í sjó í desember á fyrsta ári ef hann var meira en 60 g. Ef bætt var salti (NaCl) í fóðrið var hægt að sleppa minni seiðum og það dró úr afföllum. Vöxturinn var svipaður og hjá Atlantshafslaxi af norskum uppruna og betri en hjá frönskum stofnum af svæðinu.

Mikill munur var á vexti í fersku vatni og sjó milli mismunandi stofna sem reyndir voru. Einnig var mikill munur á kynþroskaaldri. Tækni við framleiðslu hrygnustofna og þrílitna einkynja stofna, sem þróuð hefur verið fyrir regnbogasilung var aðlöguð að urriða með góðum árangri. Frammistaða geldra hrygnustofna var sambærileg við tvílitna samanburðarhópa.

Rannsóknir standa yfir á næringarþörfum urriða. Bráðabirgðaniðurstöður benda til þess að hann þurfi hærra hlutfall hvítu (próteins) í fóðri en aðrar tegundir, sérstaklega regnbogasilungur.

Illa hefur gefist að ala urriða í sjó fram að hrygningu. Athuganir sýna að hrognalosun seinkar og afföll hrogna aukast. Urriðinn virðist vera áhugaverð tegund fyrir eldi í sjó í Frakklandi. Aðeins þarf eitt ár í sjó til að framleiða 1,5 kg fisk og 8 mánuðum seinna er hann 3,5 kg ef notaður er hrygnustofn.

## INTRODUCTION

Brown trout (*Salmo trutta*) originally widely distributed from the area surrounding the Mediterranean basin to north Scandinavia and Soviet Union, and from Spain to the Caspian sea. The species present a wide variety of sedentary and anadromous populations (Figure 1), adapted to various river and lake systems in which two or more morphologically and behaviourally recognizable forms may be found (Gordon, 1959). Recent reviews of the genetic differences between European stocks have been provided by Ferguson (1989) and Guyomard (1989).

Brown trout has frequently been transferred outside its natural range, for more than a century. The purpose was generally to acclimatize the species in rivers or lakes, for establishing a recreational fishery. As opposed to the numerous attempts to introduce salmon species to new environments, which failed in most of the cases (Harache, 1988) the transfer of brown trout has resulted in the establishment of self reproducing populations throughout the world. It is now a resident species on all continents, including north America. In the southern hemisphere where it has been successfully introduced, either in the very early days of fish transplantations, e.g. Tasmania in 1864 (Walker, 1988), and Chile in 1905 (Boeuf and Medina, 1991), or more recently in the subantarctic isles of the Kerguelen archipelago (Davaine *et al.*, 1982).

Many stocks of brown trout have been reproduced in European hatcheries for several decades, mostly for the purpose of producing fry and fingerlings for stocking depleted populations, subjected to an intense sport fishery. In France, the hatchery stocks take their source from ancient crosses between natural populations, possibly including sea run stocks, and constitute a rather homogenous genetic entity (Krieg and Guyomard, 1985; Guyomard, 1989), relatively close to the group from the Atlantic French coast. The attempts to farm brown trout in fresh water for human consumption, led to the conclusion that it was not a competitive species, compared to rainbow trout (*Oncorhynchus mykiss*), which grows faster and has the reputation of being easier to rear.

Only a few attempts to assess the potential of the species for marine aquaculture are described in the literature (Refstie and Gjedrem, 1975; Gjedrem and Gunnes, 1978; Refstie, 1982). They demonstrated, the possibility of rearing the species in brackish or sea water but the strains used expressed lower growth rates than Atlantic salmon. Consequently the species was not considered to be suitable for competitive marine productions in northern Europe. In France, early attempts to farm the species in brackish or marine waters have been described (Ledoux, 1973; Landrein, 1977), but did not lead to significant developments.

**Figure 1**. Repartition of brown trout in Europe and localisation of some geographic and ecologic forms (adapted from Guyomard, 1989). ▬: *Salmo trutta trutta*, 1: *Salmo trutta fario*, 2: *Salmo trutta lacustris*, 3: *Salmo trutta macrostigma*, 4: *Salmo trutta marmoratus*, 5: *Salmo trutta carpio*, 6: *Salmo trutta dentex*, 7: *Salmo trutta labrax*, 8: *Salmo trutta caspius*, 9: *Salmo trutta letnica*.
*1. mynd. Útbreiðsla urriða í Evrópu og útbreiðslusvæði nokkurra afbrigða.*

## THE CONTEXT OF MARINE AQUACULTURE IN FRANCE

Freshwater trout farming is an active industry in France, using sophisticated and very intensive techniques. The production relies almost exclusively on rainbow trout with an annual production of 35 000 tons in 1990. Plate size trout is the most common product, though diversification in sizes is sought by the most dynamic enterprises. Such enterprises usually use sterile and monosex populations (Chourrout, 1980) to produce large trout destinated partially to the smoking industry. However, the limitation of appropriate water supply limits this production to a few thousand tons. Marine farming in coastal waters has been investigated as a possibility to increase and diversify the production. To date the activity remains modest, with a production of about 1000 tons in 1990.

The hydrological characteristics of the French sea shore makes the coastal waters quite “challenging” for the various species of salmonids reared in sea water. They are characterized by mild winter temperatures which allow an excellent growth for most species, but elevated temperatures in summer on some locations, with important inter-annual variations (Figure 2). The salinity generally remains at high levels (34–36‰) all year round. The combination of these high summer temperatures and salinities result in unfavorable conditions for salmonids, especially during summer months. They are critical for adult rainbow trout which exhibits summer mortalities at all marine sites (Harache and Faure, 1986), and also at the post-smolt stage for Atlantic (*Salmo salar*) or coho salmon (*Oncorhynchus kisutch*). Both salmon species undergo a critical period generally affected by non negligible summer mortalities (Harache and Boeuf, 1986; Harache and Gaignon, 1986). Existing French marine salmonid farming is thus limited to a short term seasonal production, mainly composed of rainbow trout of intermediate size (1.5 to 2.5 kg), produced over an autumn-spring period. The production of salmon remains limited to a few hundred tons, and the overall activity is facing a slow development due to the difficulty of remaining competitive with foreign salmonid products, which are invading the French market. Total imports of Atlantic salmon have exceeded 55 000 tons in 1990, including 40 000 tons of fresh farmed products from northern Europe (Anonymous, 1991).

Under the pressure of the increasing availability of products, whose size and price are adequate, the French consumption of smoked salmonids have been growing rapidly over the past decade. In the mean time, the evolution of the French trout farming industry, now producing a more important proportion of a large trout, have provided opportunities of developing large smoked trout identified as a competitive product facing an increasing demand from the industry. The present mariculture production does not matche the demand due to the difficulty of successfully producing substantial quantities of large size trout (2 to 3 kg) all year round.

**Figure 2**. Water temperature in the two SEMII experimental sites.
*2. mynd. Hitastig vatns á tveimur tilraunastöðum, þ.e. annars vegar í söltu vatni og hins vegar í fersku vatni.*

## THE DISCOVERY OF BROWN TROUT PERFORMANCES IN SEA WATER

After the preliminary trials cited previously, new attention was given to the species by Boeuf and Harache (1982) who compared the osmotic adaptation of brown trout, rainbow trout and coho salmon to high salinities. They then studied the euryhaline response of brown trout in comparison with brook trout (*Salvelinus fontinalis*) and their hybrid the "tiger trout" (Boeuf and Harache, 1984). This study was a complement to a program evaluating the possible crosses between salmonids, the results concerning the fresh water phase were summarized in Blanc and Chevassus (1979, 1982). These works confirmed the possibility of adapting yearling brown trout to sea water of high salinity in the spring. Such fish demonstrated an excellent marine growth allowing them to reach an average weight of 2 kg in October, 18 months after sea water entry, in spite of a very high incidence of sexual maturation. But the most striking point was the evidence of a much better resistance to summer conditions and resultant high survival when compared to rainbow trout controls.

These results encouraged more investigations, realized jointly by INRA and IFREMER, to assess the aquaculture potential of brown trout. This included studies concerning the whole life cycle (reproduction, rearing techniques, sizes and dates for sea water transfer, genetic improvement and nutritional requirements). Specific results about the genetics and nutrition studies are given in detail in other contributions (Chevassus *et al.*, 1991; Arzel *et al.*, 1991b). Other results are presented hereafter.

## THE REARING OF JUVENILES IN FRESH WATER

There is much less literature corncerning the optimal requirements of brown trout compared to that of rainbow trout, however several works allow to characterize the species. During yolk sack absorption, brown trout present similar development patterns as Atlantic salmon and Arctic charr (*Salvelinus alpinus*) for temperatures above 8°C, but differences are found at lower temperatures where *Salmo trutta* shows an intermediate response between Arctic charr, which develops faster, and Atlantic salmon, which requires more time to reach the stage of first feeding (Jensen *et al.*, 1989).

According to Elliot (1975) the optimal fresh water growth is obtained at 13°C, in agreement with McCauley and Casselman (1980) which give the range 12–15° for optimal growth; these temperatures are below the temperature preferred by rainbow trout (15–17°C) and Atlantic salmon (15°C). The "optimum fresh water temperature range", defined as the range over which feeding occurs and there is no abnormal behaviour stretches from 4 to 19°C (Elliot, 1981). Preliminary works suggests that the thermal tolerance to lethal and sublethal temperatures in fresh water (26–27°C) is slightly higher than that of rainbow trout (Happe, personal communication). Maxime *et al.* (1988) showed that the oxygen consumption of brown trout is lower than that of rainbow trout of comparable sizes for the same temperatures in fresh water (40% less at 17.5°C).

Under "normal" temperature conditions of the maritime regions of north-west France, first feeding usually occurs in the second half of February. The early growth of the species is usually slower than that of rainbow trout, but faster than that of Atlantic salmon (Figure 3). It seems to be easily improvable, as in fact very little work has been carried out to adapt the "standard" techniques used for rainbow trout to the specific needs of the brown trout. The use of an artificial substrate during the yolk sack resorption phase, has been shown to improve the survival and initial growth (Krieg *et al.*, 1988). The growth observed during the fresh water phase varies widely among the different populations available (Chevassus *et al.*, 1991). Subsequently

**Figure 3**. Early growth of brown trout, rainbow trout and Atlantic salmon (Krieg *et al.*, unpublished data). $RT_1$: Commercial strain of rainbow trout reared in Brittany. $RT_2$: INRA strain (North America origin) of rainbow trout. $BT_1$: INRA synthetic population of brown trout. $BT_2$: INRA strain of brown trout (Center of France). $AS_1$: Norwegian strain of Atlantic salmon (introduced from Matredal, Institute of Marine Research, Bergen). $AS_2$: French strain of Atlantic salmon (naturalized Scottish population, used for release in the south-west of France). All six groups were reared in the same farm and the same diet.
*3. mynd. Vöxtur nokkurra stofna af urriða, regnbogasilungi og Atlantshafslaxi á seiðastigi.*

the choice of an appropriate strain, well adapted to the rearing conditions is essential. Due to the need of a certain size at a given time for a successfull adaptation to sea water, only a certain part of the population can be transferred during the first autumn. Selecting the most precocious spawners, in order to allow a supplementary growth period during the first year, as well as techniques optimizing the initial growth of the fry are the most immediate solutions which can be used in order to transfer a larger proportion of the population into sea water. The application of photoperiod control techniques developed for rainbow trout could be of use for advancing the spawning time.

As opposed to a common belief once applied to the rearing of Atlantic salmon, brown trout juveniles do not require shallow water to thrive in raceways. The species is easily reared in circular tanks with 0.8 to 1 m of water and a fast current (10 to 20 cm/s at the periphery). It seems essential to allow the feed to sink slowly in an helicoidal movement in order to make it available for the fry and fingerlings during a long period. Under these conditions, brown trout has an excellent spatial repartition, allowing to reach high densities (up to 40 kg/$m^3$) without apparently affecting the performances (Faure, personal communication). Typical growth curves obtained at the IFREMER/INRA Experimental Station are given in Figure 4.

**Figure 4**. Growth curves obtained in the SEMII experimental freshwater facility (from Faure, 1991).
*4. mynd. Vöxtur urriða í tilraunum í fersku vatni.*

Brown trout are quite susceptible to external parasites such as *Costia* spp., and like Atlantic salmon, it is highly sensitive to furonculosis infections caused by *Aeromonas salmonicida*. A carefull sanitary management is thus necessary to avoid the development of outbreaks, especially as furonculosis is ubiquous in the rivers of western France.

## DEVELOPMENT OF OSMOTOLERANCE AND SEA WATER ADAPTATION

The wild populations of brown trout present a wide variety of morphological and ecological characteristics. The existence of "sedentary" forms resident in lakes or rivers, and "anadromous" forms raises the question of a possible difference in salinity tolerance between stocks. This led to early works, which came to the conclusion that Scottish populations of anadromous and non-anadromous brown trout were not expressing significant osmotic and ionic differences when exposed to sea water (Gordon, 1959).

Further studies helped to define the physiological status of some different strains available in France. A spring raise of the gill Na+ K+ ATPase activity has been observed in yearlings of a domesticated anadromous population originating from south-west France, whereas other hatchery populations from Brittany considered as "sedentary" did not show any seasonal enzymatic activity modification (Boeuf and Harache, 1982, 1984). A more rapid adjustment of the body fluids after a direct exposure to full sea water was found in the "smolting" population, confirming the existence of a high degree of osmotolerance of "sea trout" also observed by Hogstrand and Haux (1985).

The development of the euryhaline response of two "smolting" hatchery reared populations of Finland was studied by Sovio *et al.* (1989), who showed some differences in the physiological pre-adaptation, and timing of the development of salinity tolerance. A spring raise of the gill ATPase activity was observed in the "anadromous" population but not in the "lake trout" one. Both populations tolerate a direct exposure to sea water, but the development of salinity tolerance was more precocious in the anadromous form. Both stocks showed a surge of the blood plasma thyroid hormone level (T4) in May, followed by a decrease of the sea water tolerance in June, the fish returning to a typical parr external appearance.

More recently, an autumnal raise of the Na+ K+ gill ATPase activity was observed in sub-yearlings of another "domestic" hatchery French population (Arzel *et al.*, 1991a). In the absence of a more complete physiological screening of wild and hatchery populations of "sea-trout" or "sedentary" stocks available in France, the distinction between "sedentary" and "anadromous" populations does not seem to be easily applicable to the existing domestic stocks, which are issued from ancient crosses having possibly implicated several populations.

**Figure 5**. Evolution of blood osmotic pressure of brown trout fingerlings (0+) after direct (D) or progressive (P) transfer to sea water (from Quillet *et al.*, 1986b). Two class-size of fish were transferred: 40 g at transfer (i), or 49 g at transfer (s). In the case of progressive transfer, salinity was regularly increased from 0 to 31% in the first 12 days of the experiment.
*5. mynd. Breytingar á flæðiþrýstingi í blóði urriðaseiða (0+) eftir beinan flutning í sjó (D) eða aðlögun (P).*

Like domestic rainbow trout, populations which do not have a physiological pre-adaptation to an hypersaline environment can perfectly adapt to sea water and thrive during certain periods if they exceed a critical size. Some comparative trials performed between a "domestic" stock considered as "sedentary" and a well identified migrating wild population of Normandy (river Orne), showed that sea water survival (both at transfer and during summer months) was not higher in the latter one (Quillet, personal communication). In most cases, brown trout requires a longer adaptation time than rainbow, before it actively feeds, and progressive adaptation to the marine environnement was found to reduce significantly the short term osmotic disequilibrium (Figure 5), and the mortalities at transfer.

Further work was carried out to define the critical sizes and the procedures to adopt, in order to obtain a satisfactory adaptation to the marine environment. Quillet *et al.* (1986b) showed that sub-yearlings could be adapted to sea water in autumn or early winter, if they exceed a certain size. Direct transfers were shown to be possible with the larger fish, but resulted in significant mortalities (22%) in smaller animals (inferior to 40 g). However, a progressive adaptation generally results in higher survival, especially for the smaller fish. After an initial period with mortality, the mode of transfer does not appear to influence long term survival or growth.

Due to the difficulty of practicing progressive adaptation to sea water on the French coast (tide amplitude, site availability), other ways of improving the resistance of the fish were investigated. Application of earlier works using sodium chloride in the diet to promote the osmotolerance of rainbow trout was thus applied to brown trout. The use of a 10% NaCl supplementation in the diet, one month before sea water transfer, resulted in a slight diminution of fresh water growth (which had been compensated after thirty days in sea water), but a significant increase of the gill Na+ K+ ATPase, and an increased survival in sea water (Figure 6), particularily for the smaller fish, (Arzel *et al.*, 1991a). This is thought to be an interesting practice, allowing to transfer successfully small size or fragile animals directly into sea water, and promoting a better post-transfer growth.

## SEA WATER REARING

### *Survival*

As previously indicated, brown trout usually exhibits a high survival rate during all the marine rearing phase, including the first summer during which it is consistently the species with the highest survival rate (Figure 7). During the second summer, survival rate is similar to that of coho salmon, and slightly better than that of Atlantic salmon. Tolerance to high salinities and temperatures is much higher than that of rainbow trout which suffers significantly high mortalities at most trout farms. This fact was confirmed by an experiment conducted on a warmer rearing site (temperature exceeding 19°C during four months), where the survival remained at 57% whereas rainbow trout controls sufferred 90% mortality (Quillet *et al.*, 1986b).

In rainbow trout, these mortalities are associated with severe physiological perturbations (Mazo, 1985). Both species of trout exhibit different metabolic reactions when exposed to high salinity. It induces a reduction of oxygen consumption indicating a decrease of the metabolic activity in rainbow trout (compared to fresh water conditions), but an increase in brown trout (Maxime *et al.*, 1988). Moreover, the haemochimic and haematologic modifications observed in rainbow trout for moderately elevated temperatures (17°C) do appear in brown trout, but at much higher temperatures.

Though this fact is still under investigation, survival rates of monosex triploid populations in the marine phase do not appear to be substancially different from that of diploid controls. However, some differences were observed recently, possibly due to a differential resistance to direct transfers to sea water (Quillet, personal communication).

**Figure 6**. Thirty days survival after sea water transfer of sub-yearling, using NaCl supplemented food (SA) or normal diet (NO) (adapted from Arzel *et al.*, 1991a).

*6. mynd. Hlutfall lifandi seiða eftir 30 daga í sjó, fóðrað á saltbættu (SA) og venjulegu (NO) fóðri.*

**Figure 7**. Typical profiles of survival during the first summer in SEMII experimental sea water cages, for several species (from Quillet, unpublished data).

*7. mynd. Einkennandi lifun urriða, regnbogasilungs og Atlantshafslax í sjókvíum á fyrsta sumri.*

Some furonculosis associated mortalities, related to fresh water infected fish were observed in sea water, but no vibriosis outbreaks occurred in the experimental facilities where all fish introduced are vaccinated. The main disease concern is due to mortalities caused by a “pancreas disease”, first observed in 1986 (Baudin-Laurencin, personal communication). These mortalities have occurred non systematically on the experimental site and at various stages in a commercial farm, including pre-harvest size, and seem to be comparable or identical to that occuring in farmed Atlantic salmon (McVivcar, 1990). Prophylactic treatments, using vitamin E and avoiding excessive feeding are thought to increase resistance to the disease.

### *Growth*

The growth of brown trout, which is rather slow in fresh water, is substancially increased in sea water as shown by several experiments. Though not resulting from strict comparison protocols (two different sites, different temperature regimes etc.), a clear beneficial effect of the marine environment has been observed (Quillet *et al.*, 1986b). At two years age, groups reared in sea water were twice as big as controls maintained in fresh water (Figure 8).

Growth rates appear to be only slightly inferior to that of rainbow trout and very similar to that of Atlantic salmon of Norwegian origin (Matredal selected strain) (Figure 9). No significant differences were found between all female triploid and normal diploid populations during the immature phase, the former continuing to grow during the normal maturation period at three years, allowing large size animals.

The use of all female stocks allows production of 1.5 kg fish one year after sea

**Figure 8**. Growth observed in fresh water and sea water for different year classes of brown trout (Quillet *et al.*, 1986a); a: autumn transfer (0+), s: spring transfer (1+).
*8. mynd. Vöxtur urriða í fersku vatni og sjó, eftir árgöngum.*

**Figure 9**. Evolution of daily specific growth rate (GR) with body weight (Wm) in fresh water and sea water for brown trout and two strains of Atlantic salmon (from Krieg *et al.*, 1991).
*9. mynd. Daglegur vöxtur í hlutfalli við þunga hjá urriða og tveimur stofnum af Atlantshafslaxi í fersku vatni og sjó.*

water transfer (December) and 3.5 kg in May of the next year after 68 weeks in sea water (Figure 10). Larger size animals (up to 6–7 kg) can be obtained when using sterile populations. Substancial growth improvements seems to be highly probable in view of the first results of the individual selection program (“Prosper”) initiated in 1986 (Chevas-sus *et al.*, 1991) and of the nutrition studies.

### *Nutritional requirements and food conversion index*

The first trials were performed with commercial trout diets, which have later been found to be far from the optimum needs of the species. Gabaudan *et al.* (1989), compared the basic protein energy requirements of two species of trout and coho salmon and showed that a significant growth improvement can be obtained when using specific diets with high protein content, corresponding to the requirements of the species (Arzel *et al.*, 1991b). Though precise monitoring of the food conversion index was not obtained precisely by experimentation, brown trout's present performances is close to that of Atlantic salmon, and better than that of rainbow trout or coho salmon, under the French environmental conditions (Figure 11).

## REPRODUCTION

### *Reproduction and long term rearing for production of large size fish*

In all aquaculture productions aiming at producing large size fish for the market, early maturation represent a serious constraint due to reduced growth, deterioration of the food conversion, and flesh quality and increased mortalities. The depression of growth during the maturation period is more pronounced when the animals are kept in sea water (Figure 12).

The French populations of brown trout normally reproduce for the first time at two or three years of age, with a high variability in the age at first maturity (Quillet *et al.*, 1986a). For a given population it was shown that the occurence of early maturation at two years is reduced for animals reared in sea water, compared to the fresh water controls, in spite of a larger size. On the average, 75% of the males and only 30% of the females become sexually mature at two years age when reared in sea water, but almost all reproduce by three year.

**Figure 10**. Growth of brown trout obtained in sea water at the SEMII experimental cage facility (no grading) (from Faure, 1991).
*10. mynd. Vöxtur urriða í sjó í tilraunum.*

**Figure 11**. Evolution of the food conversion index with size (preliminary data from Faure, 1991).
*11. mynd. Fóðurnýting urriða við mismunandi þunga.*

These results suggested that monosex all female populations should be used when planning the production of intermediate size fish (1.5 to 3 kg), and all female triploid stocks when looking for the production of large animals (3–6 kg). Subqsequently, the techniques developed for rainbow trout (Chourrout, 1980) have been applied and adapted to the brown trout (Quillet *et al.*, 1991).

### *Broodstock maintenance and egg production*

Reproduction in captivity does not create specific problems in fresh water, occurring from early November through late December. Maintenance of the broodstock in full sea water until reproduction generally results in increased pre-spawning mortalities. For a given population (Krieg, unpublished data), ovulation is delayed (Figure 13) and a diminution of the relative fecundity (no. of ova/kg) is observed. However, the absolute numbers of eggs per female are higher, and eggs are significantly larger in sea water.

## CHARACTERISTICS OF THE PRODUCT AND APTITUDE TO SMOKING

Brown trout being a "new product", it was important to characterize the quality of harvested fish, in comparison to other products on the market, either "fresh" or "smoked". Appropriate investigations were thus initiated with several co-workers including INRA and IFREMER specialized laboratories.

External aspect of brown trout may be penalizing at least in the initial attempts to introduce the product on the market. Colour is generally less silvery and more "steel grey" than salmon with a high variability, especially in the occurence of black and red spots. The external aspect seems to be highly dependant upon the surrounding environment, and a yellowish colour may prevail in fish reared in small cages. This inconvenient colour is much reduced when the brown trout are in large size cages.

Proximal analysis of the fresh whole product, indicated that brown trout was closer to Atlantic salmon than other farmed products available. It showed important composition differences with triploid rainbow trout (much lower fat content), and only slight differences from farmed Atlantic salmon of comparable size (higher ash and sligthly lower lipid content). Preliminary results showed

**Figure 12**. Effect of sexual maturation of 2 year-old males on their growth, when they are reared in fresh (FW) or sea water (SW) (Quillet *et al.*, 1986a). R is the weight of mature males in percent of the weight of immature fish of the same group.
*12. mynd. Áhrif kynþroska tveggja ára hænga á vöxt þeirra. R sýnir þunga kynþroska hænga sem hlutfall af ókynþroska fiski í sama flokki.*

**Figure 13**. Evolution of the ovulation in the females of two strains of brown trout in fresh water (black symbols) and sea water (white symbols) (Krieg and Legall, unpublished data).
*13. mynd. Hrognalosun yfir tíma hjá urriðahrygnum af tveimur stofnum í fersku vatni (svört tákn) og í sjó (ófyllt tákn).*

that large size brown trout (all female population) give intermediate yield (weight of final product on fresh round weight) between Atlantic salmon and triploid rainbow trout at all stages of transformation: carcass, whole filet, pealed and prepared filet and smoked filet, (Faure, 1991). Further studies are on way to characterize more precisely the suitability of large brown trout for various forms of processing (flesh texture, heterogeneity of raw material, effect on cooked product). Blind organoleptic and gustative tests, operated by a specialized jury, concluded to an equivalence with Scottish farmed salmon if not superior. Alterations of the flesh caused by a myxosporidian organism was observed on several occasions, after slaughtering. This problem found also in farmed rainbow trout, as well as in wild caught fish is under closer investigation (Baudin-Laurencin, personal communication).

## CONCLUSION

A considerable amount of scientific data has been accumulated during the last five years on the biology and rearing technology of brown trout. The rearing performances in sea water have been consistently good over the last five years, with an excellent growth and a high survival. Few severe problems have developed, and significant growth improvements have been obtained by the first experiments on specific nutritional requirements. It is probable that rearing technology could be more effectively adapted to brown trout. Moreover, the application of selective breeding techniques seems able to allow a rapid and substancial improvement of the rearing performances.

Although the actual production remains at a pilot scale in France (no more than 20 tons produced annually), the surprising characteristics expressed by brown trout, should lead to the development of a production adapted to French marine environmental conditions. It remains to date the only real opportunity to produce large size animals of high quality, all year round, with stable results. The projected economic perspectives, based upon the results obtained on pilot scale productions seems promising (moderate cost of juvenile and efficient food conversion) and may help trout growers to diversify their production in minimizing their production costs.

Several industrial size projects are in under way and should lead to a production of several hundred tons in the next two years. This should allow a more precise evaluation of the place of this local “sea trout” on the national market, both in a fresh form or for the smoking industry.

From a general point of view, this example shows that a careful examination of the potential of indigenous species, taking into account the possible high variability of “unselected genetic materials” may lead to interesting discoveries, susceptible of industrial developments.

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