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Turbot (*Scophthalmus maximus*) Grow-out in Europe: Practices, Results, and Prospects

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Abstract

Turbot farming is an emerging industry with a total production of 5,500 metric tonnes in Europe in 2000 (only 5% of sea bream and sea bass production). The market situation at the moment is favourable for turbot. This paper provides an overview of the major features of turbot grow-out methods that are in the public domain and describes the results of rearing studies done with an Atlantic strain of turbot, both in the laboratory and by the industry. Turbot farming has developed mostly in land-based systems supplied with sea water at ambient temperature, or most often heated. Rearing methods are highly diversified among sites. Under the most intensive rearing conditions, stocking densities average 45-50 kg m^{-2} and fish are fed dry pellets manually. Growth results are highly dependent on environmental conditions, mainly the average annual temperature. The best growth rates are obtained at about 14-19°C. To reduce heating costs, there is now great interest in re-circulation systems in several countries. This paper also discusses the gap between the observed growth potential and the usual growth results in the light of recent applied scientific research. Major growth improvements may be obtained by using the optimal thermal regime, by increasing oxygen concentration to near saturation and by feeding fish correctly near apparent satiety. Since efficient commercial diets are now available, dietary composition is the main determinant of flesh quality. Selection of fast-growing and late-maturing fish is another way to improve growth of turbot.

Key Words: turbot, growth, rearing methods, ecological factors, nutritional factors.

Introduction

The European fish farming industry was dominated by rapidly expanding hatcheries in the late 1980s and 1990s. About 450 million juveniles of the European sea bass Dicentrarchus labrax and gilthead sea bream (*Sparus aurata*) and 5 million juveniles of turbot (*Psetta maxima*, also called *Scophthalmus maximus*) were produced in 1999. High-quality juveniles are produced by intensive rearing methods. Turbot is more difficult to rear than sea bass and even sea bream, but production in hatcheries is still consistent with the intensive rearing method and the extensive method is no longer in use (Shields, 2001). There are few turbot hatcheries and France Turbot is the leader. This French hatchery has to adjust its production to the world market demand to avoid overproduction of juveniles. Due to important improvements in larval rearing methods, the average survival is about 20% from hatching to 5 g juveniles (range 10-40%). Developmental abnormalities (skeletal malformation and bad pigmentation) have been significantly reduced during the last decade, so that over 80% of the 5 g juveniles produced are sold.

Turbot farming is a recent and small activity, with a total production of 5,500 metric tonnes in Europe (Spain and France) in 2000. European turbot production is only 5% of sea bass and sea bream production (47,000 metric tonnes of sea bass and 57,000 metric tonnes of sea bream) from 8 countries in 2000. Turbot farming has developed more in land-based systems. At the moment, the market situation is more favourable for turbot than for sea bass and sea bream. Turbot prices have increased over the last decade and demand has increased, partly as fisheries catch has stabilised around 7,600 metric tonnes since 1997.

This paper provides an overview of the grow-out methods for turbot and the results obtained in the laboratory and by the industry. The paper also discusses the recent scientific research on how and to what extent growth can be improved by manipulating environmental, nutritional, and genetic factors. Only the major changes in grow-out technology in the public domain in the last decade are considered (Person Le Ruyet *et al.*, 1991; Lavens and Remmerswall, 1994). This paper does not describe how to grow turbot to make maximum profit, and it does not provide any reference to *Scophthalmus maeoticus*, a closely related species found in the Black Sea that is also involved in aquaculture projects (see proceedings of this workshop).

General Rearing Methods

Rearing methods are extremely diversified from country to country and from farm to farm, so the following general trends are only indicative. The production cycle has an on-growing phase and a grow-out phase.

On-growing phase

At the end of the hatchery-nursery phase, juvenile turbot weighing about 10 g (4-5 months post-hatching) are ready for a 4-5 month on-growing phase in indoor facilities, usually a greenhouse or a cheap industrial building supplied with heated water (by flow-through or re-circulation systems). Turbot are reared in shallow tanks (concrete or fibreglass circular or square tanks or concrete raceways) with 10-20 m^2 surface area and 0.25 to 0.50 m useful depth. Stocking density is relatively low, about 10 kg m^{-2} at the start increasing to 30 kg m^{-2} (about 150 fish m^{-2}) at the end of the phase. The first grading, which is done when fish are about 50-60 g, marks the end of the on-growing phase.

Expanded pellets obtained by extrusion cooking process that were partly rehydrated and softened by the addition of 15-20% water have been replaced with dry pellets of a smaller size about a decade ago. Pellet size must be adjusted to fish size and preferably semi-continuously delivered to the fish to maximize growth. Buoyancy of the pellets is important as small fish ingest them during their slow descent to the bottom. The use of non-floating pellets (sinking pellets) is recommended to promote food ingestion and growth at the start of the on-growing phase but feeding practices may be changed towards the end.

As there is often a decrease in water quality during the on-growing phase in comparison with hatchery phase, there is serious risk that juveniles develop bacterial and/or viral diseases that are not specific to turbot (Toranzo *et al*., 1997). To prevent diseases, turbot are most often vaccinated against vibriosis and furunculosis. In some sites, they should be vaccinated against bacterial diseases caused by *Flexibacter* and *Streptococcus*. Turbot are also highly susceptible to parasite infestation, mainly by the ciliates *Trichodina* and *Uronema*. Fish are given formalin baths once a month to limit parasites. In some farms, water is partly UV-treated. Each farm has its own policy.

Turbot growth during the on-growing phase depends on temperature, feeding conditions, and on juvenile quality in terms of capability to adapt to the environmental conditions at the site. The growth potential of turbot during the first year is high: fish weighing 200 g at 9 months and 350 g or more at 12 months (Figure 1). But the growth rates obtained in production farms are markedly lower, about 60-75 g at 9 months in almost all farms with the same thermal regime. Survival is in the range 85-75%; the better the water quality, the higher the survival. The high efficiency of commercial dry pellets for on-growing allows an apparent food conversion rate of about 0.8, even with fish mortality accounted for.

Grow-out phase

Intensive rearing conditions are used for turbot grow-out. Turbot can be reared in a variety of tanks and raceways most often gathered under cheap industrial buildings. Individually covered outdoors tanks are rare and floating sea cages (first tested in sea ponds, sheltered bays, or estuaries in France and Spain) have been suppressed recently in France and Spain. Tank volume increases from 25 m^3 to 100 m^3 as fish grow, but the useful depth is 0.70 m or less even with large fish.

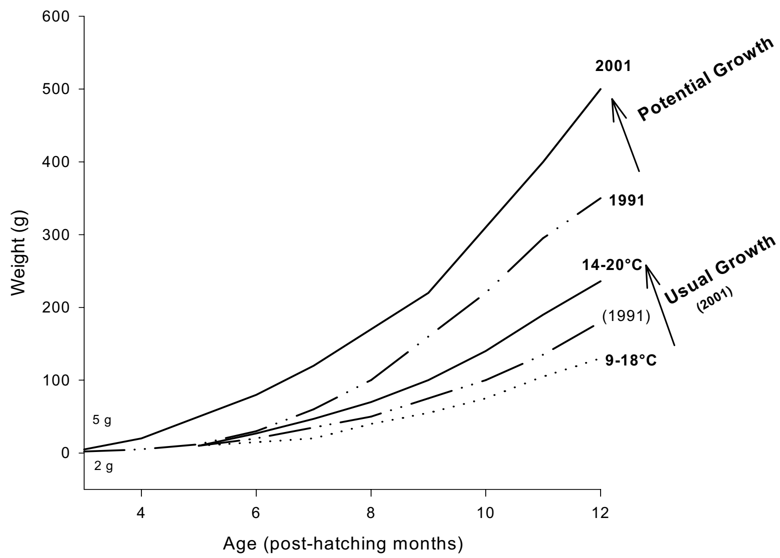

Figure 1. Potential and usual growth of turbot during the first year.

Land-based farms initially had flow-through rearing systems but re-circulation systems are now developing rapidly. In farms with sufficient geothermal water supply (low-cost heated water), water can be used several times without special treatment except oxygen supplementation. In practice, first-ranked tanks loaded with small fish are supplied with better-quality water than last-ranked tanks loaded with large fish. To reduce heating cost to a minimum, the tendency of turbot farms is to reuse water after specific treatment and limit fresh sea water supply to 5-10% of water volume per day. Pilot re-circulation systems supporting 20 tonnes of annual production have been tested in France 10 years ago for turbot (Blancheton, 2000). Some commercial grow-out farms are now partly operating with re-circulation systems and other projects are at the planing stage (Ireland, Scotland).

As turbot can tolerate overcrowding (up to 4 layers of large fish), stocking density may be very high (over 100 kg m^{-2}). In the most intensive rearing systems, stocking densities per useful surface area are about 30-35 kg m^{-2} of 300 g fish, 45 kg m^{-2} of 750 g fish, and up to 60-80 kg m^{-2} of larger fish. To increase the resting surface available for the fish, tanks can be fitted with 1-2 rigid netted carpets about 30 cm off the tank bottom. Some fish move from the tank bottom to the upper water level as soon as it gets too crowded. In farms using less intensive rearing conditions (and most often flow-through water systems), the stocking density is only 30-35 kg m^{-2}. Whatever rearing system is used, stocking density averages 45-50 kg m^{-2} during grow-out. It can be increased up to 60 kg m^{-2} for fish over 1 kg during the fattening period.

During grow-out, it is advisable to maintain fish sizes homogeneous, despite laboratory data that showed that regular grading did not promote growth. Fish are calibrated by automatic machines and sorted into several size classes at least twice during grow-out. Repetitive handling has little effect on the health of the fish.

A wide range of diets is suitable for grow-out of turbot. Commercial success was first accomplished by farms using trash fish in Great Britain. The same feeding practice has been used in Northwest Spain for turbot fattening for several years. The use of trash fish as feed depends on availability and price and may lead to deterioration in water quality and slow growth and poor flesh quality in turbot. French farmers were the first to use dry pellets for turbot, and these are now in common use for grow-out anywhere.

Feeding large fish correctly is more difficult than feeding young fish. Feeding methods applied in production farms are diverse and poorly defined. Turbot are most often fed by hand twice a day during summer and once a day during winter. To facilitate visual monitoring of feeding (very difficult in large tanks when stocking density is high), one solution is to use floating pellets (only in open rearing systems). Fish are fed in excess and uneaten pellets are netted one hour after. The apparent food conversion ratios average 1.2-1.3.

Barring major disease problems (nutritional pathology included) and/or technical problems (water supply disruption or accidental pollution), survival of turbot is near maximum during grow-out. However, growth is highly variable from site to site and is mainly dependent on temperature regime. Turbot can reach 3 kg or more at 3 years of age (Figure 2). This fast growth rate was achieved several years ago in small and large farms using trash fish and heated water in Great Britain. Similar growth rates are

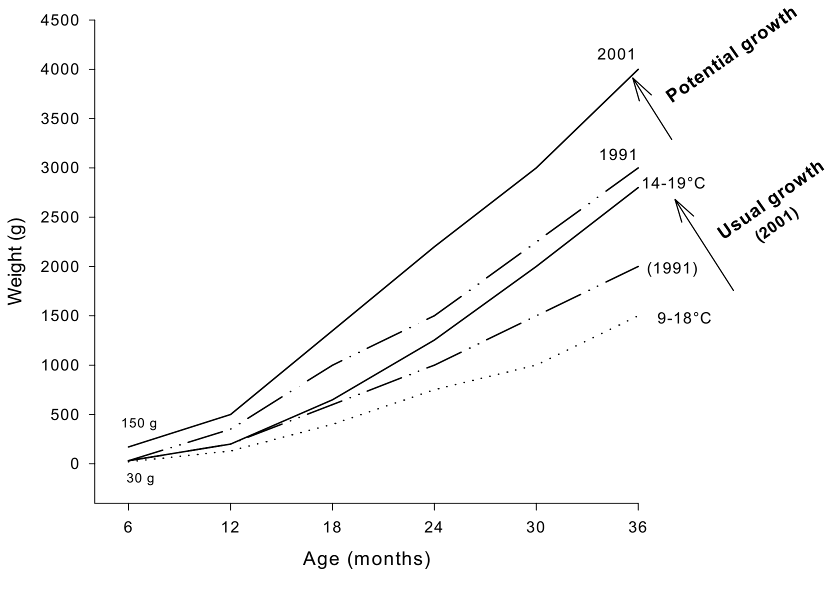

Figure 2. Potential and usual growth of turbot during the first 3 years.

regularly obtained in production farms using dry pellets and geothermal water when the annual temperature range is 14-19°C. In Spain, where ambient temperature range is 14-18°C, turbot 2-2.5 kg are routinely produced in less than 3 years (1 kg at 18 months). However, where the seasonal temperatures range from 9 to 19°C, a weight of 1.2-1.5 kg is obtained only in 3 years (750 g at 2 years), half the maximum growth potential of turbot.

Harvesting and Processing

Turbot can be marketed at sizes from 0.5 kg to 4 kg, with larger fish commanding higher prices. Because demand is higher than supply, there is not at the moment any major competition between farmed and wild turbot. Wild turbot are larger and have a higher price. Most farmed turbot are marketed at an average weight of 1 kg (0.8-1.5 kg) priced at 9 Euros per kg in 2001. There is also much interest in large fish of 3-4 kg, mainly in Spain, at a high market price. Such market for large fish takes up 10-20% of the production of some French farms. During the last decade, an increase in market demand for pan-size turbot and a decrease in fish size from 750-600 g to 500 g have been observed.

Farmed turbot are usually marketed whole and fresh (60-80% of French production). Large fish can also be sold as fillets; this market is still very limited but it will probably develop in the future. Due to an increasing demand for live turbot in Asian countries and some European cities, there is now interest in marketing turbot alive (now done by three of five French farms). With special pre-conditioning and packaging, turbot can survive up to a 2 d without water, and survival can be over 85% after 18 h transport without water.

Turbot farming is still an emerging industry in Europe, and production has been increasing: 270 mt in 1987, 3,327 mt in 1997 and 5,390 mt in 2000 (Table 1). This production comes from farms in Spain (70% of 2000 production), France (18%), and Portugal (9%). There is also a small steady production (50-200 mt) in UK-Ireland and Norway. Main European market is Spain. In Chile, turbot farming started in 1992 and an initial production of 17 mt was obtained with juveniles supplied from Europe and technical support from Great Britain. Chile produced 210 mt in 1997 and 450 mt in 1999 from juveniles supplied locally and most of the turbot is exported to Asian countries and USA.

Although turbot productivity during grow-out is much lower than the productivity of salmon farms, it is a profitable activity for about 5 years, at least in France. The profit margin is about 1.3 Euros per kg, but as for sea bass and sea bream, a decrease in market price with increase in turbot production should be expected in the future. The production efficiency of turbot farming may be improved in many ways:

- by decreasing the purchase price of juveniles (about 1 Euro per 5-10 g juvenile for several years now), which accounts for 18% of total production cost
- by increasing the feeding efficiency and growth (feeds represent 17% of total production cost)
- by optimizing the rearing methods to lower the labor cost (16% of total production cost), increase the operational stocking densities, and reduce mortality risks.

Factors Affecting the Growth of Turbot

Fish growth depends on available energy resulting from the difference between metabolised and maintenance energy. Metabolised energy depends on feed intake (food consumption), food digestibility, and food composition. Maintenance energy represents losses due to excretion, digestion, other metabolic processes, and the energy cost for adaptation to rearing conditions. Fish growth is thus affected by any factors that influence feed intake: ecological factors (water quality), food availability (access to food and feeding time), nutritional factors (energy content of the diet), and any rearing conditions leading to the establishment of social interactions in a group (stocking density, culture system). Fish growth is also dependent on internal (nervous, hormonal, and neuroendocrinological) factors. Our purpose is to discuss how environmental, nutritional, and biotic factors may be manipulated to achieve maximum growth at minimum cost and produce high-quality fish.

Table 1. Turbot harvest production (metric tonnes).
Sources : Ofimer and ICES, except for Chile (Alvial and Manriquez, 1999).

	Spain	France	Portugal	UK-Ireland	Norway-Denmark	Chile
1995	800	800	82	0	55	20
1996	1,500	850		5	110	180
1997	2,225	950	150	5	145	250
1998	2,250	900		<100	<100	210
1999	2,083	1,000	378	<100	100	300
2000	3,683	1,000	510	<100	200	450

Environmental factors

The long-term effects of major ecological factors on turbot growth have been extensively studied and reviewed (Person Le Ruyet *et al.*, 1997; 2001; Person Le Ruyet and Bœuf, 1998; Pichavant *et al.*, 1998; 2000; 2001; Bœuf *et al.*, 1999; Person Le Ruyet 2000; Imsland *et al.*, 2000a; 2000b; 2001). Ecological factors are generally classified as determining or limiting factors. Temperature, salinity, and light are commonly considered as determining factors because they act directly on receptors to decrease or increase growth. In contrast, limiting factors operate below a minimum threshold required (e.g., oxygen), above a maximum (e.g., ammonia), or outside an ideal range (pH-CO_2). Limiting factors can also include nitrite, nitrate, suspended solids, meteorological factors, and chemical pollutants, and medicines.

The primary response of fish to a change in environmental conditions is a decrease in appetite without changes in feeding efficiency. Consequently, specific growth rates are strongly correlated with food intake as will be shown below. Effects on growth and even survival are dose and time related (depend both on ambient concentration and on exposure duration).

Temperature: Except tunas and a few other big pelagic fish, fish have body temperatures close to ambient, and thus metabolic activity and growth are determined by water temperature. In 40-50 g turbot of the Atlantic strain, the optimum thermal range for growth is 16-19°C. In 10 g turbot, the optimal range is shifted +2°C to 16-22°C. Turbot growth rate decreases rapidly below 14°C and above 20°C. The lowest and highest water temperatures at which turbot stop feeding are 5 and 25°C during the on-growing phase and 8 and 22°C during grow-out. Specific growth rates and feed intake rates are similarly related to water temperature (Figure 3). A slight increase in the apparent feed conversion (otherwise constant at 0.8-0.9) is most often observed at 20°C and suggests an upper tolerance limit that has been confirmed by physiological indicators.

Salinity: Turbot can adapt to salinity as low as 10‰, but die at 6‰; there is no data on tolerance to high salinity. In 1-5 g turbot, minor changes in feeding activity and growth have been most often observed between 35‰ and 10‰ under optimal temperatures. A significant improvement in weight gain has been reported in a 3-month experiment on 3 g turbot: weight gain was 8% higher at 19‰ than at 35‰, without apparent change in feed intake Some enhancement of growth may be expected by rearing juveniles at an intermediate salinity of 20‰, especially at the thermal range of 18-22°C (Imsland *et al.*, 2001).

Light: Light includes a complex of ecological factors such as intensity, photoperiod, and colour spectrum. Laboratory and field data clearly show that the appropriate light intensity must be provided to fish, and the timing of feeding relative to light conditions is crucial to feeding. Feeding is low but not stopped under full darkness, whereas the use of abnormally high light intensity can lead to cessation of feeding due to behavioural disturbances.

The long-term effects of photoperiod have been extensively studied as it is considered to have greater effect on growth than light intensity. However, turbot exposed for 2 months to constant photoperiods (8, 12, or 16 h light per 24 h), to continuous illumination (24 h light), or to changing photoperiod (increasing from 12 to 16 h light per day or decreasing from 12 to 8 h light per day) showed no significant change in feed intake and growth when feeding was unrestricted and light intensity was optimal at 200 lux at the water surface. Under certain rearing conditions, long photoperiods may be used to stimulate feeding activity.

Oxygen: Among the limiting factors, oxygen is the major one. There is some risk of oxygen depletion in sea cages and in land-based systems when high stocking density is used without O_2 supplementation. The minimum oxygen required for maximum growth in turbot is 6 mg l^{-1}. Feeding stops at 3 mg l^{-1} O_2 and

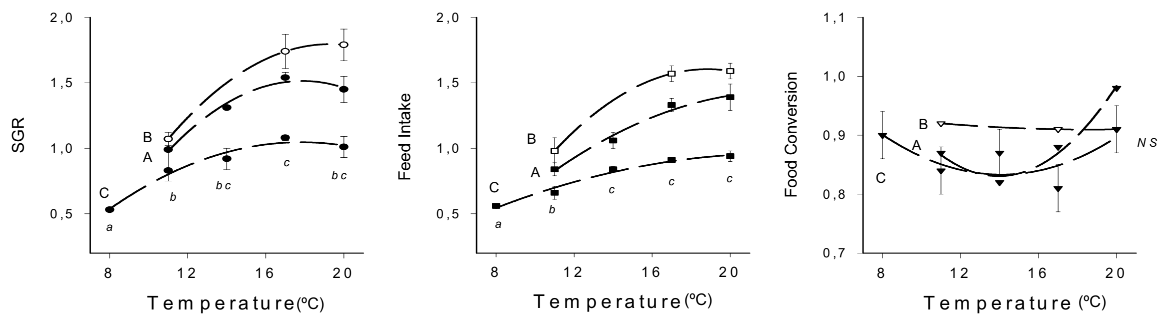

Figure 3. Effect of temperature on specific growth rate (SGR), feed intake (% fish biomass) and food conversion in 3 batches of turbot (initial weight 40-50 g). Statistically different means are indicated by different letters ($p<0.05$); NS, not significant.

the lethal concentration is 0.75-1.3 mg l^{-1} O_2. When turbot are exposed to repetitive severe hypoxic shocks (from 75-100% to 20% air saturation), growth is reduced due to lower feed intake and lower food efficiency (Person Le Ruyet, unpublished results).

Under hypoxic conditions, despite feeding to satiation growth at 3.2 mg O_2 l^{-1} is 39% lower, and that at 4.5 mg O_2 l^{-1} is 30% lower than in normoxic or O_2-saturated water (Figure 4). Feed intake at 3.2 mg O_2 l^{-1} is 40% lower, and that at 4.5 mg O_2 l^{-1} is 23% lower than in normoxic water. Food conversion ratios are 11% and 19% higher at 4.5 and 3.2 mg O_2 l^{-1} respectively under hypoxic conditions. Growth is not significantly different between fish fed to satiation under hypoxia and fish fed a restricted ration in normoxia.

Whereas major growth improvements may be obtained by rearing the fish in O_2-saturated water, there is no biological risk when O_2-supersaturated water is used. When turbot are reared in water containing O_2 at 147% and 223% air saturation, there is no significant effect on feed intake, food conversion, and growth over a 30-day period (Figure 4). In O_2-supersaturated water, there is an increase in body fat deposition under unrestricted feeding, which is rather an adverse effect.

Ammonia: Fish growth may also be strongly affected by the level of a natural pollutant, ammonia. Threshold concentrations of ammonia that allow growth are modulated by exposure duration and affected by O_2, pH, and many biotic factors (fish size, early life history, health status). Under otherwise optimal rearing conditions, the ammonia threshold concentration for acceptable growth over three months (growth 10-20% lower than in the control) is 5-6 mg l^{-1} total ammonia or 0.2 mg l^{-1} NH_3 at pH 7.5. These ammonia concentrations may be reached in land-based farms operating at high stocking densities. Concentrations below 2-3 mg l^{-1} total ammonia may be considered safe levels. The 96-h lethal concentration (LC_{50}) is about 40 mg l^{-1} total ammonia and feeding is stopped at 20 mg l^{-1}. The 30-day LC_{50} is about 20 mg l^{-1}. Growth is primarily dependent on feed intake and food conversion in ammonia-exposed fish is not affected as long as feeding activity is sufficient (Figure 5).

Nutritional factors

As long as turbot are fed to satiation with nutritionally well balanced diets, no major improvement in growth may be expected from different feeding regimes because turbot are very efficient feeding regulators. For the turbot industry, optimisation of feeding procedures with regard to feeding behaviour is important. Dietary composition is an important determinant of flesh quality. Research in turbot nutrition is now focused on fish flesh quality (how specific diets may be used to modulate final fish flesh quality), fish meal substitutes (by plant protein sources), and highly digestible diets (with low waste and easy-to-collect faeces to facilitate water treatment in re-circulation systems).

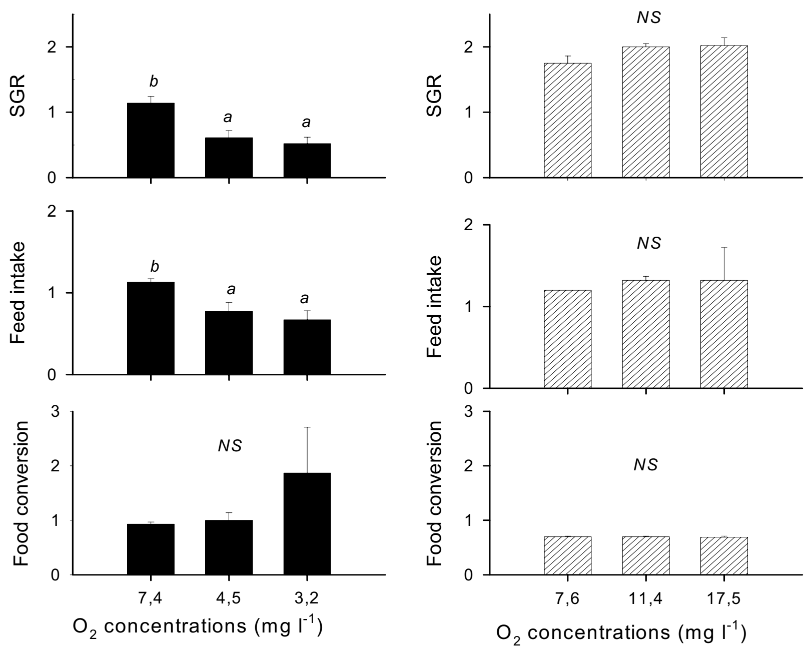

Figure 4. Effect of ambient oxygen concentrations on specific growth rate (SGR), feed intake (% fish biomass) and food conversion in 60-100 g turbot. Statistically different means are indicated by different letters (p<0.05); NS, not significant.

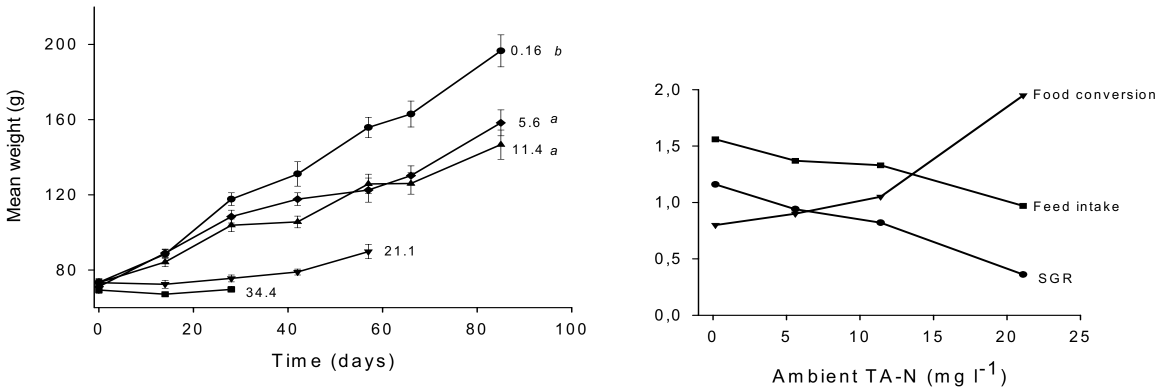

Figure 5. Effect of ambient total ammonia concentrations on growth of turbot (left graph), and on specific growth rate, feed intake (% fish biomass) and food conversion (right graph). Statistically different means are indicated by different letters ($p<0.05$); NS, not significant.

Nutritionally well balanced diets: The amount and balance of nutrients in the diet should cover the requirements of turbot. These nutritional requirements are well known and stay the same in relation to fish size during the on-growing and growth-out phases (turbot however have different requirements for reproduction). A protein content of 55% is recommended for turbot diets, and the amino acids required may be provided when high-quality fish meal is the main protein source. Higher protein levels are more efficient (the best growth of 10 g turbot has been obtained with 60% protein) but too expensive. Protein levels of 45-50% lead to a certain sparing of protein through increased incorporation of marine fish oil. Lipid levels exceeding 12% should be avoided when at 55% protein because they lead to excessive fat deposition in the fish. The fatty acid requirements of turbot are secured by diets with 10-12% lipid from marine fish oil plus soy oil. Energy levels of about 18 MJ kg^{-1} are adequate during grow-out. Incorporation of 10% pre-cooked starch is required for processing expanded pellets (extruded pellets). Turbot has no specific mineral and vitamin requirements. The nutritional requirements and diet composition of turbot diets are detailed in Guillaume *et al.*, 1991; 1999; an example diet is given in Table 2.

Table 2. Composition and formulation of a typical grout-out diet for turbot (Guillaume *et al.*, 1999).

Main constituents	g kg^{-1}
Fish meal	300
Fish protein concentrate	200
Soybean	100
Wheat meal	145
Wheat middlings	150
Fish oil	50
Soy oil	20
Vitamin premix	20
Mineral premix	10
Binder (pre-cooked potato starch)	20 (100)
Total Proteins (g kg^{-1} DM)	*480-520*
Total Lipids (g kg^{-1} DM)	*120*
Digestible Energy (MJ kg^{-1})	*18*

Dry pellets over trash fish or moist pellets : Turbot can adapt at any age to dry food. During the on-growing phase, dry pellets have definitely replaced pellets that are rehydrated by the addition of 15-20% water. Trash fish and moist pellets are used with dry pellets for broodstock. Dry pellets are less palatable than rehydrated or moist pellets, and they are often ingested in smaller quantity and digested more slowly. Dry pellets are also not as efficient as moist pellets or trash fish. In turbot production farms, weight gain was 18% lower with an experimental expanded pellet than a moist pellet (25% trash fish and 75% commercial diet) of similar 54% protein content (Figure 6). The lower weight was due to the diet change and initial growth retardation; afterwards, the growth rates were similar (growth curves were parallel) although the variability in fish weight was lower with dry pellets than with moist pellets.

When turbot are fed wet squid, they fill most of the stomach, whereas they would ingest dry squid at only 20% of the volume of wet squid (Grove *et al.*, 2001). Gastric emptying time is 3 times longer with dry squid than with wet squid.

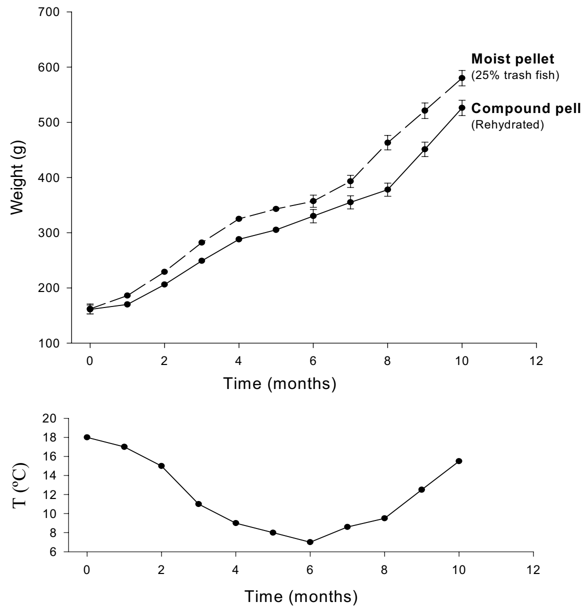

Figure 6. Comparison of turbot mass increase when fed moist pellets and compound re-hydrated pellets in a 1980 experiment carried out at ambient temperature (production scale).

Optimal feeding procedures: Feeding procedures must be optimized to limit food deprivation and water pollution. Manual feeding is still the most common way to feed turbot to apparent satiety. In the laboratory, satiety is easily gauged by visual observation of the fish from above the water. Food supply is stopped as soon as there are 1 to 2 uneaten pellets. The duration of the meal depends on fish appetite (about 15 min for a group of 50-100 fish) and fish are fed as often as necessary, once a day in large fish and twice a day in juveniles. Fish are fed at specific times according to preference, and the best feeding time depends on environmental conditions at the farm.

In production farms, manual feeding of fish is difficult; visual observation of fish is impossible in large tanks when stocking density is high and the water turbid. It becomes difficult to deliver to the fish the right daily food ration, without feed waste or limitation. Large fish eat less food per unit weight than small fish (daily food ration is 1% of biomass in 100 g turbot and less than 0.5% in 1 kg fish) and they eat less often but larger amounts of food per meal. To prevent food limitation, fish in flow-through systems may be fed non-floating pellets in excess. In highly turbid water when classical feeders are used, the changes in sound of turbot during feeding may be used to command feeding stopping (Lagardère and Malleck 2001). Self-feeders (demand feeders) are not in current use despite promising results in the laboratory (Burel *et al*., 1997) and more recently at a production scale.

Consequences of voluntary or accidental food restriction on growth performances are well documented and are marked (Figure 7). After a severe food restriction, turbot become transiently hyperphagic when fed in excess, but the observed compensatory growth could not completely compensate for lost growth. Food reduction also induces growth heterogeneity (Saether and Jobling, 1999).

Use of high-energy diets: The commercial diets for turbot on-growing and grow-out have high protein contents, 52-54% of dry matter, and low crude lipid content, about 12%. Diets with 20% lipids and 53% protein are now used for the fattening turbot over 1.5 kg to meet the specific Spanish market demand for fish with a high fat content. High-fat diets were first developed to limit water pollution, but due to adverse effects on fish flesh quality, they are less and less used.

Dietary composition is an important determinant of flesh quality, but no improvement of growth is expected from usual feeding regimes. Body fat content is positively correlated with dietary fat content, and turbot compensates for a low-lipid diet by a higher feed intake (Saether and Jobling, 2001). Turbot 200 g in weight fed a diet with 43% protein and 17% or 25% lipid show no significant change in protein content and weight gain after two months. Among 820 g turbot, diets with 60% protein and 20-25% lipid affect growth and whole body composition adversely: higher fat deposition in whole fish and high fat accumulation in subcutaneous tissues (rather than in muscle or viscera) than diets with 10% or 15% lipid (Regost *et al*., 2001).

Genetic factors

The relationship between genetic variation in wild or farmed populations of turbot and their physiology or growth is poorly known. Genetic variability is mainly characterised by dinucleotide microsatellites, which are neutral markers, rather than functional markers such as allozymes or other biochemical indicators (Iyengar *et al*., 2000).

Genetic selection to improve growth: A classical way to improve growth of turbot is to select populations in terms of growth capacity, environmental preferences, or physiological capacity to adapt to specific rearing conditions. Differences in the optimal growth temperature exist among different geographic populations of turbot. The growth rates of a Norwegian population of 7 g turbot reared at 18 and 22°C are higher than those of Scottish and French populations. The optimal temperature is higher, too, 23°C instead of 20-21°C. In young turbot, the optimal temperature for growth is functionally related to three types of haemoglobin; it ranges from 19 to 23°C due to differences in the oxygen-binding proprieties

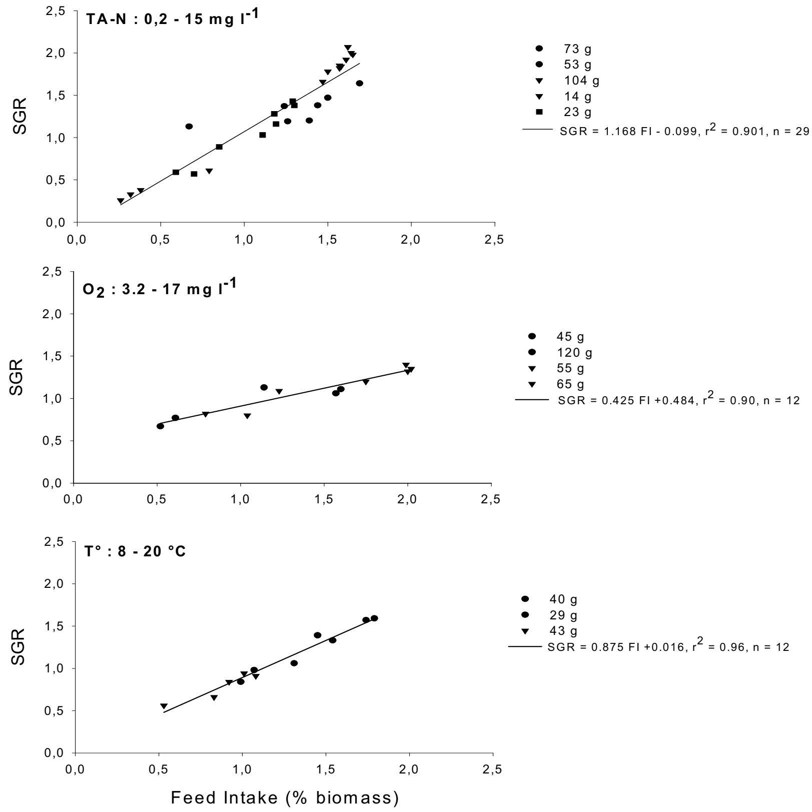

Figure 7. Specific growth rate (SGR) and feed intake relationships versus (from top to bottom) ambient ammonia, oxygen and temperature.

(Imsland *et al*., 2000). These growth results should be confirmed in larger fish with regard to age at first maturity.

Genetic solutions to sexual differences in growth: Individual variation in growth performance observed in turbot during grow-out may not be exclusively explained by rearing conditions, but also partly by sexual differences in growth. Female turbot are larger than males, and differences in growth rate between females and males occur before sexual maturity, at about 500 g. Size differences with sex increase with age; older males weigh 10-20% less than females of the same age (Figure 8). Males also mature at 2 years of age (less than 1 kg), one year earlier than females. There is a high interest to produce all-female or sterile stocks to avoid the loss in growth caused by sexual maturation before the fish reached the market size.

Little data on genetic manipulations exist in the public domain because applied research on turbot genetic is mainly carried out by the industry. The basis for induction of triploidy is the same as for other species (Piferrer *et al*., 2000). Progress in induction methods is needed to improve the initial slow growth among triploid turbot. The benefits of triploidy is probably relatively low in turbot as in sea bass (Felip *et al*., 2001). Other ways may be used to delay maturation in fish, such as manipulation of environmental factors (temperature, photoperiod) or selection of strains with later onset of sexual maturity.

Conclusion

Major improvements in turbot growth may be obtained by using the optimal thermal regime, by increasing oxygen to near air saturation, and by feeding fish correctly near apparent satiety. As very efficient commercial diets are now available, dietary composition is the main determinant of flesh quality. Selection of fast growth late-maturing fish is probably another way to improve turbot growth.

On the other hand, the optimisation of rearing systems will contribute to the reduction of production cost. The use of sophisticated re-circulation systems in many countries (France, Great Britain, Chile) reduces the dependence of farm on climatic conditions. Because re-circulation systems have high investment and energy costs, high stocking densities should be used in them as long as fish quality and fish welfare are not affected.

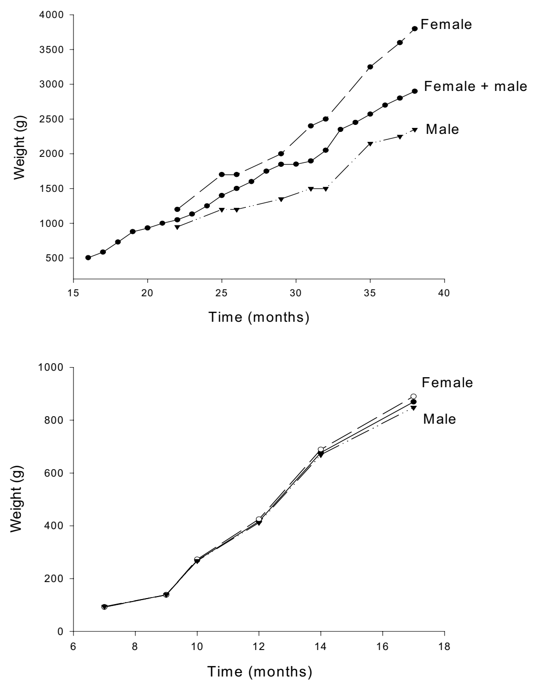

Figure 8. Mass increase versus fish sex, from top to bottom in large and in young turbot.

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