CULTURE OF TURBOT (*SCOPHTHALMUS MAXIMUS*)

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INTRODUCTION

Turbot, *Scophthalmus maximus* Rafinesque, 1810: *Psetta maxima* Linnaeus, 1758, is a marine demersal carnivorous flatfish of the Scophthalmidae family, relatively abundant in Europe: from 68°N down to Morocco 30°N. It is also abundant in the Mediterranean Sea as far as Turkey. But it is lacking in the Black Sea, where two very close species, *S. maeoticus* and *S. ponticus*, are naturally found (Figure 1). Turbot are caught on sand, gravel, or mixed bottoms at a depth of 20 to 70 m. The total annual catch is less than 10,000 for all Europe in spite of the high market price: from 10 to 25 U.S. $/kg according to the country and the size of the fish (0.65 to 15 kg).

Turbot was selected for aquaculture in the early 1970s, both in the United Kingdom and France due to its commercial value and its potential growth rate in intensive conditions. Initially the main work was performed at state research centers including MAFF* and the former WFA** (now SFIA) in the U.K., and the former CNEXO*** (now IFREMER†) in France. Efforts have been focused on larval rearing techniques, egg supply and live prey production. The first larval metamorphosis to juvenile stages in the laboratory was obtained in 1970 and 1972 in the U.K. and France, respectively. In contrast, the research efforts on the growout of juveniles has been limited in France, whereas in the U.K. sea-caught young turbot have been used by commercial companies for about 10 years to establish the basic growout techniques.

In the last decade, in both the U.K. and France, significant progress has been made in understanding the nutritional and environmental requirements of turbot as well as in hatchery design and management. The development of turbot culture has been limited by the lack of high quality juveniles during the past decade. Only recently has this culture become a profitable business in the U.K.

BROODSTOCK MANAGEMENT

The development of turbot hatcheries depends on the control of the production of eggs issued from captive spawners. The first spawning technique for turbot consisted of collecting eggs fertilized naturally in the tanks, with or without hormonal synchronization. Now natural maturation followed by stripping gametes from males and females is preferred in hatcheries.

SPAWNER CONDITIONING

Most hatcherymen do not trust broodstock raised only in the hatchery. Therefore, some spawners are still obtained from the wild. Only immature fish weighing 0.5 to 2 kg are selected. While growing to maturity, the fish become acclimated to the captivity in 5 to 40 m³ sand-bottom tanks (maximum 10 kg/m²). This ongrowing and adaptation period lasts an average of 2 years.

** WFA: White Fish Authority, now SFIA: Sea Fish Authority, Marine Farming Unit, Ardtoe, Acharache, Argyll, Scotland.
*** CNEXO: Centre National pour l'Exploitation des Océans, Centre de Brest, France.
† IFREMER: Institut Français pour l'Exploitation de la Mer.
FIGURE 1. Geographic distribution of turbot and level of production: catches (open half-circles) and farming (hatched half-circles). The production is proportional to the area (different scales for catches and farming).

The spawners are kept in five age or weight classes. The females range from 3.5 to 8 kg, the males from 2 to 7 kg. The oldest fish are replaced every year. The sex ratio is 1:1.

The broodstock is fed on trash fish at the mean annual rate of 13 to 17% per week for the youngest, and 5 to 9% for the biggest spawners (wet food/biomass). In addition, the fish receive vitamin supplements especially vitamins C and E (600 and 80 mg/kg fish/week of vitamins C and E, respectively) by injection or addition to the food 2 months before spawning.

Turbots are treated against various parasites in spring and autumn, i.e., before and after the spawning period. Copepods are eradicated by 1 ppm Neguvon® directly poured into the aerated tanks while water supply is stopped (24 h bath). Formalin (200 ppm) against *Trichodina* (two 20-min baths spread over 1 week). With these treatments, the mortality of spawners rarely exceeds 10% per year.

Maturation is mainly determined by photoperiod. It occurs with increasing photophase between 8.5 and 16 h of light per day. The gametogenesis normally lasts 5 months, but may be shortened to 3 to 4 months when temperature exceeds 16°C; fertilization of the eggs does not occur above this temperature. The optimal temperature of spawning is 14 ± 1°C for 15 to 16 h of light per day. By manipulation of temperature and photoperiod, eggs can be obtained all year around with a spawning period of 2 to 3 months.9,10

**COLLECTION OF EGGS**

Each female may spawn several times, up to 12 spawns per season at a 3- to 6-d interval. Stripping should occur every 4 to 5 d. The number of eggs collected per kg female over the spawning season is very variable, averaging 430,000. The average number of viable embryos produced by artificial fertilization depends on the delay observed between the ovulation time and the stripping.

After stripping, eggs and sperm are mixed without seawater. Five to ten min later, clear seawater is poured over the cells. The eggs are then placed in the incubators. The mean value of the viability rate (embryos issued from eggs stripped) is 33%. Similar results may be obtained with natural spawning.
The incubation phase is critical. Mechanical and thermal shocks must be minimized, especially at morula stage and just prior to hatching. Incubation lasts 3 to 7 d depending on the temperature. Environmental conditions recommended are given in Table 1 and the IFREMER incubator is shown in Figure 2. The average hatching rate obtained is 78% from the viable morula egg stage. Since the egg diameter (which ranges from 0.98 to 1.18 mm) is correlated to reserves, it is supposed to be a criterion of quality.

Using the above conditioning, stripping, and incubation techniques, approximately 60,000 viable larvae are obtained per kg female per year. The cost of turbot larvae is around 10 times higher than those of seabass or seabream larvae produced under similar conditions.

**FRY PRODUCTION TECHNIQUES**

Fry production techniques can be classified as either extensive or intensive.

Extensive culture techniques are used mainly in Norway and Denmark. Large tanks or ponds are prepared for the introduction of newly hatched larvae in order to provide sufficient amounts of suitable prey. The main advantages are a low labor cost and the high quality of fry obtained. However, this ecosystem approach can only be controlled to a small extent, results are rather unpredictable and the production season is limited. Intensive culture techniques are most common.

In intensive techniques, larvae are produced at more or less high densities, and fed on live prey produced in separate tanks. Two methods have been developed: the “green water” technique (Great Britain) where algae are put in larval rearing tanks to maintain the growth of rotifers and to improve their food quality and the “clear water” technique (France) where prey are added daily to the rearing tank in the quantity required by the larvae. This latter technique will be described in the following section for the facilities of IFREMER, Brest.

**HATCHERY DESCRIPTION**

Water supply (Figure 3)—Sea water is pumped with a submersible pump and delivered to a settling tank. It is then pumped again into concrete reservoirs in an elevated position which allows gravity flow to the hatchery. Flow is regulated by a centrifugal pump. Water is filtered through a pressurized sand filter and then heated (tungsten heat-exchanger) or not, depending on the temperature required. The initial larval rearing temperature must be similar to the final incubation temperature. In any case, before use, water must be passed through a degassing column to avoid any problems of supersaturation. A UV germicidal lamp is placed on the hatchery water inlet. In the hatchery, water temperature is regulated both by inflow water and by air conditioning.

**ENVIRONMENTAL CONTROL**

Values of environmental parameters are given in Table 1. A good homogeneity of water quality (and food distribution) must be assured by both an appropriate water circulation inside the tank and a gentle aeration to avoid any mechanical stress.

**PRODUCTION OF FOOD**

Feeding regimes—The nauplii of calanoid copepods seem to be the most efficient first food for turbot larvae because of their fatty acid pattern which resembles that of newly hatched turbot larvae. Unfortunately, for the moment, the controlled production of these copepods appears very difficult at a commercial scale. The live prey used, in all hatcheries, are the rotifer *Brachionus plicatilis* and the Brachiopod, *Artemia*. However, the nutritional quality of these prey must be corrected to cover the requirements of turbot larvae for n-3 highly unsaturated fatty acids with a carbon chain >20 (n-3 HUFA). This requirement is
### TABLE 1
**Environmental Requirements of Turbot and Recommendations at Different Rearing Stages**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Temperature (°C)</th>
<th>Oxygen level (ppm)</th>
<th>Salinity (ppt)</th>
<th>Routine water renewal (%/h⁻¹)</th>
<th>Illumination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spawners (at spawn)</td>
<td>13—15</td>
<td>9.5—17</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Incubation</td>
<td>13—15</td>
<td>9—17</td>
<td>?</td>
<td>25—35ᵇ</td>
<td>50</td>
</tr>
<tr>
<td>Larval</td>
<td>18—20</td>
<td>16—22</td>
<td>6</td>
<td>?</td>
<td>5—30</td>
</tr>
<tr>
<td></td>
<td>(lethal)</td>
<td></td>
<td>5—25</td>
<td>(d 1)(d 20)</td>
<td>9—18</td>
</tr>
<tr>
<td></td>
<td>(stop eating)</td>
<td></td>
<td>2—30</td>
<td></td>
<td>24 L or 18 L/6D</td>
</tr>
<tr>
<td>Weaning</td>
<td>18—20</td>
<td>?</td>
<td>4</td>
<td>Above values recommended</td>
<td>50 to 100</td>
</tr>
<tr>
<td>Ongrowing</td>
<td>16—18</td>
<td>2—30</td>
<td>3</td>
<td>20—27</td>
<td>About 50</td>
</tr>
<tr>
<td></td>
<td>(lethal)</td>
<td></td>
<td>5—25</td>
<td></td>
<td>Excessive intensity detrimental</td>
</tr>
<tr>
<td></td>
<td>(stop eating)</td>
<td></td>
<td>8—22</td>
<td>Above value recommended</td>
<td>About 50 or less</td>
</tr>
</tbody>
</table>

* In Brest, France.

ᵇ For Baltic strains these values are 15 and 20, respectively.
FIGURE 2. Principle of the automatic incubator used at IFREMER. For large numbers of eggs incubated, the iron support is elongated in order to support 5 incubators 40 to 50 l which are submerged in large tanks: (a) water supply; (b) compensatory tube; (c) outflow; (d) flowmeter; (e) clamps; (f) plastic mixing container; (g) water inlet; (h) PVC basket carrier (440 x 440 x 230 mm) with bottom made of perforated PVC in which 16 x 1-l incubators (100 x 100 x 190 mm) with a plankton net bottom (205 μm) can be placed; (i) Crouzet motor with a speed of 1 rpm; (j) 35-l tank (510 x 510 x 260 mm). (From Devauchelle, N., Aquaculture, 58, 297, 1986. With permission.)

estimated to be near 2% of the dry weight of live food organisms. That is why rotifers and artemia must be enriched with a food containing a high level of HUFA before delivering them to fish larvae.

Rotifers—At the IFREMER, Brest Center, a semicontinuous procedure is used: the rotifer population is maintained around 200 animals per ml; each day a quarter of the volume is harvested and the tank is filled again with a new medium. Previously, the medium was an algal culture (Platymonas suecica, 2·10⁶ cell per ml). To lower the production cost, the original medium was replaced by 2/3 baker yeast in full salinity water + 1/3 algal culture (on a dry weight basis). More recently it was again replaced by baker yeast dispersed in 18
This technique allows the production of rotifers with a sufficient level of n-3 HUFA. Cultures must be limited to 2—3 weeks to minimize the risks of bacterial contamination.

**Artemia**—After hatching, *Artemia* nauplii (10 to 20 per ml) are ongrown for 48 h in vigorously aerated sea water at 24°C ± 1. They are fed on a compound diet (Table 2), at a daily ration of 40 to 60 and 60 to 80 mg/l on days 1 and 2, respectively. *Artemia* are filtered through a 150-μm mesh screen and washed in clear sea water.

**Enrichment technique**—Enrichment of live prey can be made by a 24-h “second” culture with algae or fish oil emulsion, or by a short 30-min bath with enrichment mixture. The purpose is to increase the total content of nutrients: fatty acids, protein, vitamins, and minerals in the larval foods. The composition of the enrichment mixture is presented in Table 2. The proportions used are 1.5 g enrichment mixture per 10⁶ rotifer and 2.5 to 5 g per 10⁶ *Artemia* metanauplii.

**Food schedule**—The food schedule for larvae is presented in Figures 4 and 5; at 19°C, first feeding occurs at day 3 post hatching. *Brachionus plicatilis*, 90 to 240 μm long (large-size strain), are convenient as first food and used for 10 d. Newly hatched *Artemia* are introduced at day 8, and gradually replace rotifers. The use of an *Artemia* strain of marine type (rich in 20:5 n-3 fatty acid) is recommended. However, nauplii are never rich enough in HUFA, and they never contain 22:6 n-3 acid which seems to be the most efficient essential fatty acid for turbot. For this reason, approximately at day 10, *Artemia* nauplii have to be replaced by 1- or 2-day-old enriched metanauplii which can then be used until conversion to artificial diets (weaning). The main difficulty in the clearwater intensive system is to estimate the daily quantity of prey needed by larvae. It is necessary to avoid both the underfeeding of larvae and the decrease of the nutritive value of uneaten prey. A standard feeding schedule is given in Figure 4. In any case, 90% of the prey distributed must be ingested within 24 h.
TABLE 2
Diets for Enrichment and Artemia Production

<table>
<thead>
<tr>
<th>Enrichment mixture</th>
<th>Artemia diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish autolysate</td>
<td>69</td>
</tr>
<tr>
<td>Brewers' yeast</td>
<td>—</td>
</tr>
<tr>
<td>Vitamin premix*</td>
<td>11</td>
</tr>
<tr>
<td>Cod liver oil*</td>
<td>10</td>
</tr>
<tr>
<td>Cholin (50%)</td>
<td>4</td>
</tr>
<tr>
<td>D.L. methionin</td>
<td>2</td>
</tr>
<tr>
<td>Mineral premix*</td>
<td>4</td>
</tr>
</tbody>
</table>

Note: Diets in g/100 g.

* Vitamin premix mg/g or IU/g = A: 200 IU; D3: 700 IU; E: 20; K: 3; thiamin: 3; riboflavin: 7; pyridoxin: 4; ascorbic acid: 300; folic acid: 3; vitamin B12: .04; inositol: 400; biotin: 1.2; Ca pantethenate: 15; Niacin: 50; B.H.T.: 6; CaHPO4: 22.9.

b 2 ppt Vitamin E is added to oil.

c Mineral premix (g/100 of Premix) = CaHPO4: 50; CaCl2: 21.5; MgCO3: 12.4; KCl: 9; NaCl: 4; FeSO4: 7H2O: 2; ZnSO4: H2O: 1.6; CuSO4: 5H2O: 0.3; MnSO4: H2O: 0.3; NaF: 0.1; Na2SeO3: H2O: 0.01; KI: 0.004; CoSO4: 7H2O: 0.002.

LARVAL STAGES

Morphology—The ontogeny of turbot larvae has been described in several new papers.22-26 The external morphological evolution for a temperature of 19°C is represented in Figure 4. Just hatched larvae are about 3 mm long, weigh between 0.1 to 0.2 mg, are symmetric, and the yolk vesicle well developed. The digestive tract is undifferentiated and closed anteriorly, and the eyes are nonfunctional. This is the embryonic period.

Between days 2 and 3, the mouth opens and exogenous feeding begins while yolk sac reserves and the oil globule are quickly mobilized and will disappear at days 5 and 7, respectively. During this vitelligenic period, important changes are observed: first differentiation of the digestive tract, heart organization (four cavities), swimbladder inflation and pronephros differentiation. After day 7, the post vitelligenic period, the pneumatic canal degenerates (disappearing at day 9), the mesonephros differentiates and the digestive tract further develops. The formation of gastric glands (day 15) may be considered as the end of the physiological larval stage. Whereas, from an anatomical point of view, metamorphosis is just beginning at day 15 with the flattening of the body and migration of the right eye. At day 30, turbot juveniles look like a small adult, but behaviorally they are still pelagic. Benthic behavior is definitely gained at day 40. Except for pepsin and lipase, digestive enzyme activities are observed very early. Therefore, the mechanisms of lipid digestion and absorption remain to be elucidated but, on the other hand, the enrichment of prey with fish oil appears to enhance larval growth.

An evolution of the color of larvae is observed during ontogenesis. Being salmon pink at hatching, larvae change to a dark brown color at first feeding and normally, between days 8 and 13, most larvae become orange-yellow. A small percentage of poor quality larvae stay dark. At early metamorphosis the color changes to white. But final pigmentation is not observed until days 20 and 25. At that age, normal or abnormal pigmentation can be clearly distinguished. Coloration abnormalities—partial or total lack of pigments—often occur at a high rate in intensively grown turbot and other flat fish. Abnormal pigmented fish tend
to become piebald (dark brown and white) when growing. The actual cause of such abnormalities remains poorly understood.

**LARVAL MORTALITY**

High mortality during larval stages is the main problem limiting the development of turbot culture. The maximum survival rate (I) shown in Figure 6 is exceptional. A survival rate of 20 to 30% during the first month is acceptable but difficult to obtain routinely. A first mortality peak (A), sometimes occurs from the beginning and is attributed to spawn quality or to stress during transfer of larvae into rearing tanks. The most typical mortality (B) occurs between day 6 and 8 and corresponds to the time unfed larvae die (Curve V). This may be attributed to the “unpalatability” or unsuitability of prey and/or the bacterial problems. This initial mortality may be followed by a chronic lower mortality with slow growth and low food intake. Another mortality peak (C) may occur between days 10 and 15, sometimes leading to the complete loss of larvae.

**Causes of Mortality**

The hypothesis of infection causing great mortality of larvae has never been confirmed by histological examinations. Cousin et al. failed to observe bacterial, viral, or parasitic attacks. Most moribund larvae they observed presented an empty digestive tract with a desquamation or an atrophy of mucosa. Other alterations may also appear in gill, skeletal muscle, liver, and heart such as hypertrophy, vacuolization and necrosis. The lesions have been attributed to starvation. However, large quantities of bacteria are often observed in the digestive tract. These bacteria may aggravate the lesions or even affect the digestive functions or block the gastro-intestinal tract. *Vibrio* and *Aeromonas* are frequently associated with turbot larvae and they are known to cause necrosis in prawns and bivalve larvae. These bacteria may be detrimental to turbot larvae too.

Bacteria associated with rotifers are also involved in the disruption of larval feeding. The disinfection of rotifers by three antibiotics previous to their distribution, improves the growth and survival of turbot larvae.
TREATMENT AND SANITATION PROCEDURES

Rotifers—Disinfection of rotifers by antibiotics is not advised and other means must be used to control the bacterial flora. Rotifer culture requires care to avoid the increase of bacterial populations, especially *Vibrio* and *Aeromonas*. The culture must be protected against the introduction of germs by disinfection not only of inlet water (UV or chlorine), but also of tanks and maintenance material. Batch culture of rotifers would be more advisable than semicontinuous culture.

Turbot larvae—Antibiotics added to the larval cultures are not a reliable method for bacterial control and increase the chances of inducing drug resistant strains. Decontamination of eggs using iodine (I-PVP: iodized-polyvinylpyrrolidone at 4%, for 5 min) is recommended. After each hatchery run, the breakdown of the system and disinfection of facilities are required.

NURSERY AND TRANSITION TO GROWOUT

At the end of the live-prey-feeding phase, turbot juveniles, still pelagic, are ready for weaning onto compound foods. Weaning success is strongly correlated with the size of larvae (or juveniles) and at present, no reliable result can be obtained with larvae weighing less than 40 mg (i.e., about 25 d post hatching) irrespective of their general state. Larger juveniles will be more resistant to stress and starvation, but it is recommended to start feeding when fish are still pelagic and feeding actively.

THE WEANING PHASE

Weaning systems—Weaning can be started directly in larval tanks 1 week before changing of facilities, but special tanks are recommended to limit handling of fish during weaning. Two types of weaning tanks are used: circular tanks with a conical or a hemi-
spherical base or, preferably, flat, circular or square tanks. The central outlet must be fitted
with a large nylon mesh basket that is taken off when inert food is used exclusively (Figure
7). Fiber glass tanks of \(2 \times 2 \times 0.5\) m are most common. Large raceways appear to be
less convenient.

Water treatment is that described for larval rearing. At this age, turbot are very susceptible
to vibriosis, and UV treatment of water is required before the fish can be vaccinated.

In contrast to larvae, juveniles withstand high densities quite well: the initial stocking
density is by 2500 fish per m\(^2\) (Table 3).

**FOOD AND FEEDING**

**Starter weaning diets**—Starter diets must be attractive and palatable; i.e., containing
food stimulants and having a soft texture. They must also be water stable to limit leaching
and to avoid an excessive pollution of tanks. Initially pastes and moist pellets, usually made
from fish flesh or mollusc flesh, mixed with a compound dry mash, were used. They were
palatable but their nutritive value was unreliable and their water stability was poor. Recently
the efficiency of dry pellets has greatly improved.\(^{31,32}\) Most elaborated dry diets available
today are expanded rehydratable, water stable pellets, as those developed at IFREMER\(^{33}\)
(Table 4). Pellets are obtained by the extrusion cooking process. Crumbles issued from a
rough grinding process are partly rehydrated by the addition of 15 to 20% water that gives
them a soft texture. Moreover, their acceptability is improved by the addition of specific
attractants dissolved in water and mixed with a vitamin and fatty acid premix. Inosine added
at a level of 0.6 to 1% of the dry matter seems to be the most efficient feeding attractant
and stimulant for turbot.\(^{32,34}\)

The nutritional requirements of turbot juveniles are partly known. Special attention must
be paid to the HUFA and vitamin contents (mainly ascorbic acid). The crude protein and
crude fat levels of weaning diets range from 50 to 60% and 10 to 15% of the dry matter
respectively.

**Feeding**—The best size for pellets depends on water content and must be continuously
adjusted to fish size (Table 5). Moist pellets used at early weaning are extruded through
630 to 1000 \(\mu\)m holes. The size of dry crumbles is generally increased from 400 to 600
\(\mu\)m (50 to 500 mg fish) to 630 to 800 \(\mu\)m (500 to 1000 mg fish) and is 1.5 mm thereafter.

Fish are always fed in excess in order to improve their chance to ingest the food particles
during their slow descent onto the bottom. So the daily food ration, expressed in % of the
biomass, decreases from 20 to 30% at the beginning to 4 to 5% by day 70 post hatching.
When weaning is progressive, the *Artemia* ration is gradually delayed from morning to
evening, from days 3 to 5 post weaning and the compound food is offered continuously.
But weaning may be direct if an automatic feeding device, with a horizontal plastic disc set
in motion by an electric motor or a belt conveyor with electric drive is used.

**Weaning results**—Weaning of 30-d good quality juveniles is fairly routine and the
results obtained in terms of survival and growth rates are reliable. In good conditions, 50%
of larvae establish artificial food intake in less than 2 d. Survival rates as high as 90% are
obtained at a pilot scale (lots of 20,000 juveniles of 100 mg initial weight). Typical growth
and survival results are given in Figures 8 and 9.

**THE ONGROWING PHASE**

**Description of the nursery**—The nursery is either a green house or a cheap industrial
building in which fish are reared in shallow large tanks such as concrete or fiberglass circular
or square tanks of about 10 m\(^2\) surface and 0.5 to 0.7 m useful depth. Recirculated systems
are commonly used to reduce the cost of heating and pumping.

**Environmental requirements**—The environmental requirements of turbot juveniles are
summarized in Table 1.
18h L/6h D
2-4 Watt/m²

compound pellets + live artemia (1 week max.)

I

PROGRESSIVE WEANING

conveyor belt

electric motor 24v

nylon net basket (180μm)

flushing system

over flow

- waste

recirculating systems

compound pellet exclusively

WATER SUPPLY

II

DIRECT WEANING

automatic feeder

retaining screen

waste

recirculating systems

FIGURE 7. General weaning conditions used for a progressive weaning or a direct weaning.
TABLE 3
Stocking Densities from Weaning
up to 1 Year

<table>
<thead>
<tr>
<th>Wet fish weight (g)</th>
<th>Age (months)</th>
<th>Number/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>1</td>
<td>2,500</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>1,000</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>500</td>
</tr>
<tr>
<td>35</td>
<td>7</td>
<td>250</td>
</tr>
<tr>
<td>75</td>
<td>9</td>
<td>150</td>
</tr>
<tr>
<td>125</td>
<td>11</td>
<td>100</td>
</tr>
</tbody>
</table>

The oxygen demand of turbot is at least twice as low compared to salmonids.\textsuperscript{35,36} The relationship between body weight \( W \) (mg) and routine metabolism (\( \mu \text{M/h at } 16 \text{ to } 18^\circ\text{C} \)) may be expressed by the equation

\[
\text{MO}_2 = 10 \ W^{0.74}
\]

In practice, the \( \text{O}_2 \) level in outlet water is usually kept around 5 ppm, but we notice that turbot juveniles, though resistant to hypoxia, are very sensitive to supersaturation.

- The tolerance of turbot juveniles to \( \text{NH}_3\text{-N.} \) is high: growth is not affected by concentrations of 0.08 and 0.14 mg/l at pH 6.8 and 7.9, respectively. For the same pH conditions the levels of zero growth are 0.30 and 0.90 mg/l respectively.\textsuperscript{37}
- pH below or above 4 and 10 are lethal and the optimal range is between 6.5 and 8.5 in unpolluted water. In practice a pH fluctuation of less than 1 unit is recommended.

The stocking biomass (see Table 3) may progress from 2 kg/m\(^2\) (2 g i.e., 3-month-old fish) to 10 kg/m\(^2\) (20 g i.e., 6-month-old fish). It is advisable to maintain sizes as homogeneous as possible, fish should be calibrated and sorted at least once or twice during ongrowing. A prototype grading device was developed but it is not yet available.\textsuperscript{38}

Food and Feeding—Details concerning food ration and pellet size are given in Table 5. As previously mentioned food must be delivered semicontinuously. High quality dry pellets are convenient ongrowing foods, provided that they sink slowly in the tank, but rehydratable feed is more palatable. Moist pellets are still in current use and fish more than 10 g are sometimes fed whole, chopped, small trash fish, despite pollution problems.

Results—Ongrowing performances are dependent on temperature and feeding conditions\textsuperscript{39} but good and reliable results are frequently obtained. The average survival rate is over 80% and the specific growth rate is high (Figure 9). Food conversion may be as low as 1.0 or less (dry matter to wet biomass).

GROWOUT

GENERAL METHODS

Compared to the nursery phase, growout methods are extremely diversified from country to country and from farm to farm. Extensive pond culture techniques, with or without extra food, have not been developed for turbot. However, turbot can be grown at high stocking densities in a large variety of onshore tanks and raceways or even in floating sea cages.\textsuperscript{7,8,40} The tank volume range is 20 to 100 m\(^3\), and the useful depth is about 1 m or more. Land-based rearing tanks are made either of concrete or of wood frame and PVC sheet. More often they are covered individually in order to limit fouling and provide reduced lighting.
TABLE 4
IFREMER Rehydratable Expanded Diets for Weaning and Ongrowing

Composition

<table>
<thead>
<tr>
<th>Expanded basal diet</th>
<th>42.0</th>
<th>8.0</th>
<th>4.0</th>
<th>3.0</th>
<th>3.0</th>
<th>7.0</th>
<th>4.0</th>
<th>3.0</th>
<th>4.0</th>
<th>7.0</th>
<th>0.45</th>
<th>11.0</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norwegian capelin meal</td>
<td></td>
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<td>Fish protein concentrate</td>
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<tr>
<td>Blood meal</td>
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<td>Hydrolyzed feather meal</td>
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<td>Brewers’ yeast</td>
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<td>Corn gluten</td>
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<tr>
<td>Wheat meal</td>
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<td>Wheat germ meal</td>
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<tr>
<td>Wheat middlings</td>
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<td>D.L. Methionin</td>
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<td>Potato alpha starch Liagel®</td>
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<td></td>
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<tr>
<td>Mineral premix, see (1) below</td>
<td></td>
<td></td>
<td></td>
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Extemporaneous enrichment

<table>
<thead>
<tr>
<th></th>
<th>Weaning period</th>
<th>Ongrowing period</th>
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<tbody>
<tr>
<td>Cod liver oil</td>
<td>4.9</td>
<td>6.8</td>
</tr>
<tr>
<td>Soy lecithin</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Vitamin premix, see (2) below</td>
<td>2.0</td>
<td>1.0</td>
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<tr>
<td>Ascorbic acid</td>
<td>0.28</td>
<td>0.14</td>
</tr>
<tr>
<td>Choline chloride 50%</td>
<td>1.2</td>
<td>0.6</td>
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<tr>
<td>BHT</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Inosine</td>
<td>0.16</td>
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Proximate Analysis of Complete Diets

<table>
<thead>
<tr>
<th></th>
<th>Weaning period</th>
<th>Ongrowing period</th>
</tr>
</thead>
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<tr>
<td>Crude protein</td>
<td>51.0</td>
<td>51.0</td>
</tr>
<tr>
<td>Crude fat</td>
<td>11.3</td>
<td>13.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(1) g per kg premix</th>
<th>(2) mg or IU per kg premix</th>
</tr>
</thead>
<tbody>
<tr>
<td>KCl</td>
<td>9.0</td>
</tr>
<tr>
<td>KI</td>
<td>0.004</td>
</tr>
<tr>
<td>Ca H PO42H2O</td>
<td>50.0</td>
</tr>
<tr>
<td>NaCl</td>
<td>4.0</td>
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<tr>
<td>CuSO45H2O</td>
<td>0.3</td>
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<tr>
<td>ZnSO4H2O</td>
<td>0.4</td>
</tr>
<tr>
<td>CoSO47H2O</td>
<td>0.002</td>
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<tr>
<td>FeSO47H2O</td>
<td>2.0</td>
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<tr>
<td>MnSO4H2O</td>
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<tr>
<td>CaCO3</td>
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<tr>
<td>MgCO3</td>
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<tr>
<td>NaF</td>
<td>0.1</td>
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Note: Data from IFREMER Brest Nutrition Laboratory.
TABLE 5
Moist Pellet Size and Food Ration Used
During Ongrowing at 16 to 18°C

<table>
<thead>
<tr>
<th>Wet fish weight (g)</th>
<th>Pellet diameter (mm)</th>
<th>Food ration (% body weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5</td>
<td>5.0</td>
</tr>
<tr>
<td>3</td>
<td>2.0</td>
<td>4.0</td>
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<tr>
<td>7</td>
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<td>3.0</td>
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<tr>
<td>10</td>
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<td>20</td>
<td>4.5</td>
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<tr>
<td>40</td>
<td>6.0</td>
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<td>60</td>
<td>8.0</td>
<td>1.0</td>
</tr>
<tr>
<td>100</td>
<td>10.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

FIGURE 8. Survival rates (upper figure) obtained at IFREMER for different years (1982—1983; 1980—1981; 1976—1980), and different kinds of food and growth results (lower figure) with expanded pellets at a pilot scale (a—maximum, b—average growth rate).

Floating sea cages have been tested in sea ponds or sheltered bays and generally are used for fish greater than 300 g. They are similar to salmonid cages, except that they are shallow (1 to 2 m maximal depth) and fitted with a flat bottom, nylon net or plastic inflexible material.

Turbot can tolerate overcrowding and densities equivalent to 75 to 120 kg/m³ of water volume. The normal operational range varies from 25 to 50 kg/m² or m³. Stocking densities are higher in tanks than in sea cages.
ENVIRONMENTAL CONDITIONS

Environmental requirements for large fish are poorly known because of the lack of controlled experimental work. Figures given in Table 1 are derived only from field observations. Reoxygenation systems must be used to maintain an adequate oxygen level.

DIETS AND NUTRITION

Since food represents an important part of the production cost of a marketable turbot, the most efficient and economic diets have to be chosen. Larger fish, which have lower feeding requirements than juveniles are fed by hand once or twice a day. A wide range of diets is suitable. In some countries whole chopped trash fish (sprat, pout, whiting, sardine, sand eel, etc.) are used as inexpensive feeds. The food conversion rate for these foods ranges from 2.5 to 3.5 on a wet weight basis. The disadvantages for their use on a large scale are their seasonal availability and unreliable nutritive value. Similar growth and conversion rate may be obtained with moist pellets (40% moisture) containing approximately 10% trash fish, on a dry weight basis.41 Though not commercially realistic, moist pellets are still in current use for fattening turbot in Europe. Their use should decrease as dry pellets become more efficient. Today, growth and conversion rates obtained with commercial dry pellets remain slightly poorer than those obtained with moist pellets or trash fish.

PATHOLOGY

Only the most important pathological conditions are reviewed here. Tumoral aspects or environmental pathology will not be discussed unless they differ from those observed in other species.

Viral diseases—Two viruses have been reported as causes of disease. A Herpes virus was found to be associated with giant growth of epidermal cells in skin and gills.42 Recently an infectious pancreatic virus (Ab serotype) was isolated from diseased 7-month-old turbot.43 The fish were lethargic and displayed muscular hemorrhages and a severe necrosis of the hematopoietic tissue. Turbot have been demonstrated to be susceptible to Viral Hemorrhagic Septicaemia (VHS) of salmonids. Diseased fish displayed the classical signs of VHS resulting in high mortality.

Bacterial diseases—Vibriosis is responsible for most mortalities of young turbot. It is a septicemic disease due to a few pathogenic strains of Vibrio anguillarum. In very young turbot, anorexia, darkening, and sudden death may be the only signs of the disease. Older
fish often exhibit a congestivo-hemorrhagic appearance: deep, necrotic skin ulcers, dropsy, enlargement and liquefaction of the spleen, petechiae on visceral and parietal peritoneum and viscera. In the chronic form of the disease anaemia is predominant, but a corneal opacity is often observed. Identification of the bacteria can be made at the laboratory in 24 hours. At present an oral technique of vaccination is effective.

In France, *Yersinia* has been recently observed in freshwater salmonids, and has also been recorded in cultured turbot. The symptoms include dropsy, congestion of the viscera, enlargement of the spleen, and a weakened condition. The bacteria are sensitive to antibiotics normally used in fish therapy. Commercial antiyersiniosis vaccines, effective for trout, should also be effective for turbot.

A case of *bacteriosis* due to *Photobacterium leiognathi* was observed in France on two-year-old fish and was experimentally transmitted to younger turbots. A hemolytic and thermolabile proteinaceous toxin quickly induced nervous system disorders and mortality. The mortality was stopped by antibiotherapy.

**Parasitology**—The most significant parasites in farming conditions seem to be ciliates such as *Cryptocaryon* and *Trichodina* which feed on the surface of the gills and skin. Their proliferation is stopped by bathing in low concentrations of formalin and malachite green. A myeloid necrosis caused by *Haemogregarina sachai* was reported from cultured turbot. Clinical signs of this lethal disease were anaemia and formation of tumor-like nodules.

Black spot disease can be observed in wild or cultured turbot when snails (*Littorina sp.*) are used to clean the tanks. Black spots are melanic responses of the host to infection by metacercariae of a trematode, usually *Cryptocotyle lingua*. The infection can kill juveniles but does not present any pathological effect in adults.

**Nutritional pathology**—Three pathological syndromes are related to nutritional problems in turbot. A muscular distrophy has been observed in juveniles, leading to scoliotic curvature and loss of equilibrium. A Hepato-renal Syndrome was characterized by a biliary hyperplasia and a renal calcinosis. More recently a *Granulomatous hypertyrosinemia* was described and shown to be due to a vitamin C deficiency. The clinical signs are hyper-tyrosinemia and the presence of muscular and visceral granulomatous nodules with deposition of crystals of tyrosin.

On the whole, both vibriosis and external parasitism are today the most significant pathological problems in turbot. Nevertheless, both can be easily controlled by adequate prevention or treatment when diagnosed early. Viral diseases represent the greatest threat to cultured turbot as for other farmed fish.

**RESULTS**

Farmed turbot can be marketed from about 0.65 to 3 kg or more, with larger fish commanding higher prices. In fact they are more often sold at a weight of 1.5 to 2 kg. Under optimum conditions farmed turbot can reach 3 kg or more at 3 years. However, weights of 2 to 2.5 kg are more realistic for temperatures of 14 to 18°C (Figure 10) which corresponds to heated water in Northern Europe, or to ambient temperature in Northwestern Spain. Along the French Atlantic coast, where seasonal temperatures range from 7 to 18°C, an average weight of 1.5 to 2 kg may be expected at the same age. Pan size fish can be obtained in less than two summers in many sites along the Atlantic and Mediterranean coasts of Europe.

Females grow faster than males and it is recommended to sex fish before sexual maturity, preferably before 1 kg, and to select females for the production of larger fish.

**HARVESTING AND PROCESSING**

Farmed turbot are usually marketed whole and fresh. Pan size turbot are sometimes sold frozen. Turbot are easy to harvest due to a low metabolic activity and a lack of epidermal
scales. After harvest turbot are graded and bled before packing.

Because demand is higher than the supply, there is not, at the moment, any competition between farmed and wild turbot. Farmed turbot has excellent flavor and its freshness and general presentation are appreciated. Even turbot with poor pigmentation are well accepted in the market place.

SUMMARY AND FUTURE EXPECTATIONS

Turbot farming still represents a very small activity in Europe, mainly because of the lack of consistency and predictability of production in hatcheries. In 1986, the demand for juveniles was 3 times the estimated production for all hatcheries in the next 2 years. The production of market size turbot has progressed very slowly: 10 t in 1976, 80 t in 1983, and 270 t in 1987, shared between farms in Spain, France, and the U.K. (Table 6).

There is now an active interest in turbot farming in Europe. A recent increase of both the number of hatcheries and ongrowing farms indicates that the production over the next few years is going to increase sharply. An increase of 3 to 5 times is expected. In Northern countries, production will be limited to sites where warm water effluent is available. The concentration of hatcheries in these countries (Table 6) is due both to the availability of

FIGURE 10. Typical growth results observed in different thermic environments: (a) heated water (15 to 20°C), (b) Spanish Atlantic Coast (13 to 18°C), (c) French Atlantic Coast (6 to 18°C).

TABLE 6
Estimated Turbot Production in Europe in 1987 and That Expected in the Near Future

<table>
<thead>
<tr>
<th></th>
<th>No. hatcheries</th>
<th>No. juveniles</th>
<th>No. growout farms</th>
<th>T</th>
<th>Expected</th>
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</thead>
<tbody>
<tr>
<td>U.K.</td>
<td>2</td>
<td>230,000</td>
<td>1</td>
<td>75</td>
<td>&gt;100</td>
</tr>
<tr>
<td>France</td>
<td>1</td>
<td>75,000</td>
<td>2</td>
<td>12</td>
<td>&gt;150</td>
</tr>
<tr>
<td>Spain</td>
<td>3</td>
<td>265,000</td>
<td>20</td>
<td>50</td>
<td>&gt;400</td>
</tr>
<tr>
<td>Norway</td>
<td>4</td>
<td>110,000</td>
<td>1</td>
<td>5</td>
<td>100</td>
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</table>
high quality water and a marked interest for aquaculture. Because of climate, many of the juveniles will be exported to Southern locations, mainly along the Atlantic coast of France and Spain. The diversification of hatchery techniques, and the use of extensive pond culture techniques in Norway is noteworthy, but the success of such techniques in the near future remains uncertain. It is estimated that 50 t of production is the minimum necessary for a profitable turbot operation. The optimum annual production for hatcheries is probably more than 200,000 juveniles per year.

With the increased use of intensive rearing methods, research of both governmental and commercial organizations should be focused on nutrition and feeding of larvae and juveniles as well as on reproductive physiology and pathology.

REFERENCES

3. Girin, M., Méthodes de production des juvéniles chez trois poissons marins, le Bar, la Sole et le Turbot, Rapp. Scientifiques et Techniques, publication 39, CNEXO (France), 1979, 3.


