Turbot - *Scophthalmus maximus*

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Biology, ecology and genetics

Distribution

The turbot, *Scophthalmus maximus*, also called *Psetta maxima* (Scophthalmidae, Pleuronectiformes), is naturally distributed in European waters, from Northeast Atlantic to the Arctic Circle (30º to 70ºN; 23ºW- 42ºE). It occurs in the Baltic and in the Mediterranean, as well as in the Black Sea, where a subspecies *Psetta maxima maeotica* has been described (1). It also exists in the Southeast Pacific Ocean (Chile) and in China, where it has been introduced for farming. Wild populations inhabit along all European coasts to North West Africa (Morocco), where it is also farmed. Clear geographical discontinuities have not been reported between populations. Though this species is not considered endangered, declines in wild catches (2) and some genetic evidence (3) suggest the existence of historical population reductions for European turbot.

Capture

With some marked oscillations during the 1980s, turbot catches yield more than 7 000 metric tonnes annually (Fig.1). In the last years a considerable proportion of total production derives from aquaculture (more than 35%), principally in Spain and France.

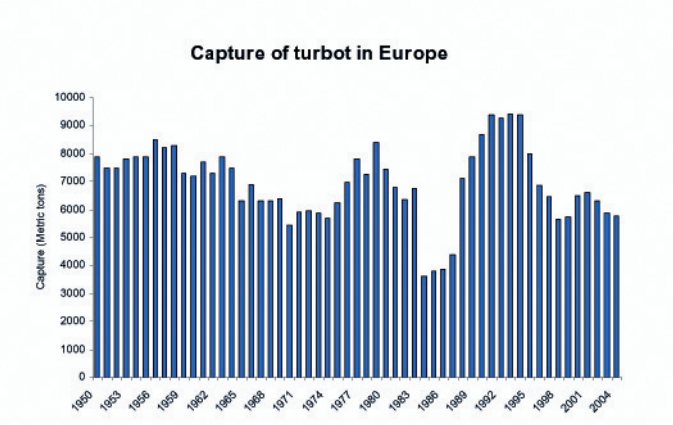


Fig. 1. *Turbot capture fisheries in Europe (4)*

Biology

The turbot is a predator species that lives on sandy, rocky or mixed bottoms; it is common in brackish waters. When juvenile, its diet is based on crustaceans: Malacostraca and Decapoda. Adults feed mainly on other bottom-living fishes (sand-eels, gobies, etc.), and, to a lesser extent, on crustaceans and bivalves. Its trophic level,

estimated from a number of food items using a randomized resampling routine, is 2.8. The turbot exhibits one of the most important growth rates observed in flatfish (around 30 cm every 3 years).

It exhibits a medium resilience, with a minimum population doubling time of 1.4 - 4.4 years (K=0.15-0.28; Fecundity=5 million). Juveniles migrate short distances, less than 10 km in the first two years of life as shown by tagging-recapture in Danish waters (5). Their migration seems to be related to tidal cycles in nursery grounds and is also associated to foraging activity. This migration pattern is followed by an increase in the offshore migration distance, likely associated to spawning behaviour.

The spawning season occurs between April and August in Mediterranean populations and between May and August in Atlantic areas. Females reach maturity at 3 years old (around 46 cm length) and males at 2 years old (around 30 cm long). Fecundity is generally over 5 million eggs. Their eggs are pelagic, smooth and spherical, of 1.1 mm diameter and an oil globule of 0.18 mm.

Population genetics

With 2n=44 chromosomes, its karyotype has been described and many chromosomes characterized by differential banding (6). There are various polymorphic genetic markers available for turbots. Variability at 17 allozymes has been described for wild European populations (7, 8). Some microsatellite loci are available in publications (3, 9, 10, 11, 12) and in the GenBank databases. Population variation at mitochondrial DNA sequences (control region) has also been described (13).

Very little is known about population structure in wild turbot. In the wild, most analyzed populations are in Hardy-Weinberg equilibrium at all loci (coding and non-coding), indicating panmixia (at random mating). In Europe, no genetic differentiation was detected between populations. It was not detected with allozymes (7), neither employing more polymorphic markers such as microsatellites; for example between Atlantic and Cantabric populations (3), and between much more distant populations such as Ireland and Norway (9). Most of the genetic variance is distributed within samples. Genetic differentiation between neighbouring populations has been reported only in one case, likely associated to physical barriers (14). In general, high levels of gene flow seem to exist for this species, as for other marine species. Low population genetic diversity at allozyme loci, compared to other flatfishes with similar habitat and life history features like brill (*Scophthalmus rhombus*) and flounder (*Platichthys flesus*), suggests historical population bottlenecks along turbot evolution (3). Discrepancy with high microsatellite variation has been explained by differential mutation rates. This hypothesis, however, has not been fully explored in turbot. More markers (mitochondrial and nuclear) should be used to analyse more populations in a wider geographical extent.

Intense gene flow between regions does not exclude the existence of genetically distinct lineages in some geographical areas. The Mediterranean turbot, for example, consists of two main genetically different lineages, one western and one eastern (13). Significant differentiation between North Sea and Baltic Sea turbot has also been described based on microsatellite loci variation (14). Multiple hybrid zones in the transition area between both seas have also been evidenced. Thus it is possible that other differences associated to geographic location appear when genetic studies are expanded for this species.

A sharp cline in genetic differentiation going from the low saline Baltic Sea to the high saline North Sea (14) suggests local adaptation to salinity conditions in these regions. Salinity conditions for optimal spawning vary between North Sea and Baltic Sea

turbot. However, scarce information exists about this point for wild turbot in other areas. There are no other published studies of fitness in wild turbot populations. It is the only known case of sharp genetic differentiation likely associated to adaptation to different environmental conditions. However, at present nothing is known of the genetic architecture of traits associated with adaptation of turbot to different environments, although they are likely polygenic as other ecologically important traits in other fish species.

Breeding and culture practices

Production

Aquaculture of turbot first started in Scotland in the 1970s. At the beginning of the 1990s the technological development of juvenile production allowed to expand considerably the production of aquaculture turbot and the number of farms. Turbot is cultured in Spain, France and Portugal but also in Denmark, Germany, Iceland, Ireland, Italy, Norway and Wales. European production has now stabilised around 5 000 tonnes per year. Spain is undoubtedly the world leader of adult turbot production (50% of the total production). Nowadays, fishery and aquaculture share almost equally the market.

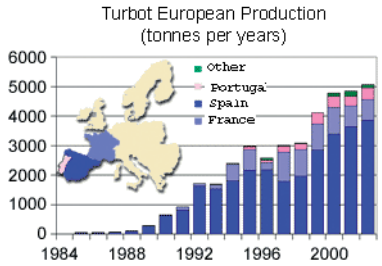


Fig. 2. *Turbot aquaculture production in Europe (15)*

Hatchery practices

Broodstocks are based on both wild and farmed individuals. Breeders are maintained in concrete or cement squared tanks (density: 3-6 kg/m^3) and fed on moist pellets. Turbot do not spawn spontaneously in captivity, thus gametes must be hand-stripped (16). As in the wild, females exhibit significantly higher growth rates than males and reach sexual maturity earlier. Males produce poor sperm in terms of both quality and quantity compared to other marine Teleosts, but females can produce 5 to 10 million eggs. Embryonic development takes 60-70 days. Spawning can be obtained all year round, modifying rearing temperatures and day-night rhythms (17). Hormones treatments can also be used to manage advanced spawning in broodstock and to obtain egg production all year round (18). Larvae survival is generally lower than in other cultured marine fishes. Newly hatched larvae, 60-70 days after fertilization, are 2.7-3.1 mm long. Larval rearing can be intensive (15-20 larvae/l) or semi-intensive (2-5 larvae/l) in tanks with open-circuit pumped seawater. At the beginning of the exogenous feeding stage (about 3 to 7 days after hatching), larvae are fed rotifers (*Brachiomus plicatilis*), *Artemia* nauplii and phytoplankton. Metamorphosis ends after 40-50 days when larvae are about 25 mm long. During 2-3 months after hatching, fishes are nursed in small tanks and start to be fed with dry pellets until they reach 5 g weight.

Grow-out

Most commonly, turbots are reared in circular concrate tanks with open-circuit pumped seawater (or increasingly in re-circulation systems). They can also be grown out in flat-bottomed metal cages (cages floating or submerged at various levels in the sea). Despite reduced production costs, culture at sea remains less used as it is not easy to find sites with adequate environmental conditions for optimal growth (e.g. temperatures around 16°C).

In both rearing techniques (land-based and at sea), turbot are fed with extruded pellets and sometimes with fresh food (fishes). Turbot tolerate overcrowding, thus stocking density can reach 100 kg/m². Commercial size is around 1.5-2 kg. Productivity of turbot culture depends mostly on fry quality, rearing temperatures and on the control of the main pathologies affecting captive individuals (vibriosis and furunculosis). Environmental factors favouring optimal growth in turbot are now well known (19, 20).

Selective breeding

Adaptation to farm environment has been suggested in this species. Cultured turbot are heavier than wild fish of the same age and length (21) and show very high incidence (96%) of abnormal lateral line canals and development differences during the larval stage. There are also some evidences that turbot farmers are selecting individuals with high growth rates to increase production and skin pigmentation.
Early sexual maturation before marketable size usually occurs in males, but also sometimes in females, compromising further growth. Consequently, turbot producers are interested in techniques allowing (i) to produce sterile stocks by polyploidisation or (ii) to obtain all-female stocks. Induced triploidy in turbot has been recently published (21). Experimental polyploidy (i.e. increased number of chromosome sets induced by altering meiotic or mitotic divisions) can produce total or partial sterility. This boost growth, prevent changes in skin color, and maintain meat quality. In turbot, induction of triploidy can be obtained by applying cold shocks shortly after fertilization (22). The growth increase observed in triploids turbot remains however relatively low (19).

Turbot show female homogamety. As females reach higher weight (10 to 20% after 800 g) and mature later, it would be advantagous, in the future, to use female monosex progenies in turbot aquaculture. Gynogenesis induction (production of offspring with exclusive maternal inheritance), one of the first steps towards the production of monosex female stocks, is already possible in turbot (23).

Information about genetic monitoring of broodstocks and cross schemes is very scarce for turbot. In the only study published to date, there is evidence of strong family structure (high coefficients of relationship between individuals) in domestic strains (3). As fecundity is very high in this species, crosses in aquaculture stocks probably involve a low number of breeders. The low effective population sizes imply a high risk of genetic erosion in domestic stocks.

The main turbot broodstock management programmes are conducted by the two most important turbot producers in Europe: Stolt Sea Farm (Spain) since 1995-96, and France Turbot (France) since 1993. They are both at the third generation of selection for increased growth and the weight gain is around 10-15% per generation. Cryopreservation for turbot sperm is commonly used for broodstock management in commercial hatcheries (24).

Restocking programmes

Experimental stock enhancement exercises (mostly financed by the European Union, national governments and the fishing industry) have been conducted on turbot in Spain, Denmark, Belgium and Norway (5, 9, 25). The efficiency of turbot restocking programmes is often difficult to evaluate as information on natural stocks abundance is rarely or only partially available. Most of these programmes were conducted with juveniles (0+ or 1+ year class), which were released on shallow coastline habitats. Released turbot generally exhibit a relatively high mortality rate, similar to that of the wild turbot (5). Although there are differences in prey and feeding behaviour between wild and hatchery turbots (19), released hatchery turbots seem to be able to adapt to natural diet within a few weeks (25). Releases of hatchery turbot have been proposed to enhance fisheries recruitment, integrated in a resource management programme of sustainable fisheries and habitat restoration.

Interaction studies

There are no studies on genetic interactions between farmed and wild turbots. Althogh no information on escape events is available, escapees are likely to be rare in land-based facilities, especially in those with water recirculation system, and are probably higher in floating cages or in open-circuit pumped seawater. In stock enhancement trials, no information is available on the ability of farmed individuals to survive, mature and migrate to spawning sites. As adaptation of farmed juveniles to the wild is good, it is urgent to investigate those aspects of primary importance to estimate the magnitude and the importance of genetic impacts of farmed turbot on wild populations. Genetic introgression and admixture of wild and domestic genomes is theoretically possible. If transgenic turbot or individuals from monosex female stocks, which are both nowadays in early stages of development, are soon produced, their impact on wild populations must also be investigated. Gynogenetic individuals are able to mature (23). Therefore, the use of triploids to ensure genetic confinment of all genetically modified individuals should soon be explored.

Conclusions/Implications

There are many aspects to be studied for this species before a proper assessment of the genetic impact of aquaculture in wild turbot populations can be performed. Some of the more urgent priorities are:

- Development of new polymorphic markers, necessary to increase the discrimination power of genetic analysis (for genetic identification of different stocks)
- Assessment of the extent of introduction of domestic genomes into wild populations, and its consequences in hybrid generations at different levels (ecological, fitness, etc)
- Assessment of traits ecologically important for turbot adaptation
- Investigation of the genetic architecture of traits associated to local adaptation and domestication

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