**Technical and Technological Aspects of Turbot Aquaculture**

This document provides an in-depth analysis of the technical and technological aspects involved in turbot (*Scophthalmus maximus*) aquaculture, encompassing biological characteristics of the species, aquaculture background, procurement and adaptation of juvenile on growing techniques, feed supply, potential diseases, and control measures.

**Biological Characteristics of Turbot**

The turbot, a flatfish within the family Scophthalmidae, holds significant economic and ecological value in both wild fisheries and aquaculture. It is predominantly distributed in the temperate waters of the Northeast Atlantic, extending from the European coasts of the North Sea. Its range also encompasses the Mediterranean Sea, the Baltic Sea, and the Black Sea, where it thrives in both coastal and offshore habitats at depths between 20 and 100 meters. Turbot is particularly abundant in shallow waters, exhibiting a benthic lifestyle, and preying on a diverse array of small fish, crustaceans, and molluscs.

Turbot's adaptability to various salinity levels, particularly in brackish environments such as the Baltic Sea, positions it as a crucial species for aquaculture in geographically diverse regions. This wide distribution highlights the species' resilience across a range of ecological conditions, from the highly saline waters of the Mediterranean to the lower salinity zones of the Baltic. As a demersal species, turbot is typically found on sandy or muddy substrates, with its growth optimized in water temperatures between 13°C and 22°C, and salinity levels ranging from 12 to 34 ppt.

Environmental parameters such as temperature, salinity, and dissolved oxygen are crucial determinants of growth rates in turbot. The species achieves its highest growth rate at an optimal temperature of 16-21°C and a salinity of 18-20 ppt. While turbot demonstrates considerable tolerance to fluctuations in salinity, extreme values below 10 ppt or above 35 ppt can negatively impact survival. Similarly, oxygen availability is critical, with a minimum dissolved oxygen concentration of 6 mg/L required to sustain optimal growth.

The reproductive traits of turbot are equally noteworthy. The species produces transparent eggs containing a single oil droplet, with egg diameters ranging from 0.9 to 1.2 mm. A mature female turbot can produce 5–6 million eggs during each spawning season, which typically occurs between April and June. Fertilization is external, and embryonic development is rapid, with hatching occurring 5–7 days post-fertilization. Upon hatching, the larvae exhibit a transparent body, a characteristic typical of many marine fish species during their early developmental stages.

**Aquaculture Background of Turbot**

The aquaculture sector has been identified by the FAO Blue Growth Strategy as a key economic activity, with a focus on its sustainable development to maximize both economic and social benefits for communities that rely on it, while minimizing environmental degradation. Within the framework of the Europe 2020 strategy, the European Union (EU) has actively promoted Blue Growth to enhance the competitiveness and efficiency of the maritime-fishing sector, aiming to stimulate employment and growth through sustainable practices. The overexploitation of global fish stocks has led to significant declines in the biomass of many fishery species. However, the simultaneous expansion of aquaculture has helped mitigate the impacts of these declines. In this context, turbot aquaculture serves as a substitute for wild turbot populations, which are increasingly under threat due to overfishing.

Historically, turbot catches reached 10,800 tons in 1970, peaking at 15,000 tons in 1979. Since the mid-1990s, however, wild turbot catches have exhibited a downward trend. By 2002, aquaculture production surpassed wild turbot catches, as overfishing led to declining stocks. In the past decade, turbot has been listed as a vulnerable species on the IUCN European Red List. Turbot biomass has experienced a significant reduction, posing a risk of population collapse. In 2015, global wild turbot catches fell to 5,415 tons, with the Netherlands accounting for the largest share at 1,761 tons.

The earliest records of turbot aquaculture date back to the early twentieth century, when the stripping method was first employed to collect egg batches. The biological characteristics of turbot, including its rapid growth rate, high survival rate, non-aggressive behaviours, and high feed conversion efficiency, have made it a leading species in flatfish aquaculture. By the 1970s, scientific knowledge surrounding turbot aquaculture had grown, following studies conducted in Scotland and France, and later in Spain during the 1980s. This research contributed to a significant increase in European turbot aquaculture production, from 40 tons in 1985 to around 10,000 tons recently.

In recent years, turbot aquaculture has expanded beyond traditional European producers such as Spain and France, with countries like Chile, China, Korea, Denmark, Germany, Iceland, Ireland, Italy, the Netherlands, Norway, and Portugal. Although turbot aquaculture began in the early twentieth century, contemporary rearing systems and methodologies vary across different countries and farms. Nonetheless, most of the turbot farming is conducted in land-based systems, where seawater is either supplied at an optimal temperature or adjusted to meet the species' specific environmental requirements. Today, turbot is ranked as one of the six most important finfish species produced within the European Union (EU), both in terms of production volume and economic value, highlighting its significant role in the region’s aquaculture industry. China has been involved in turbot production since 1992, when the first live turbot specimens were transferred from Europe. Since then, China’s turbot farming has grown considerably, with production exceeding 60,000 tons, making it a key player in global turbot aquaculture.

**Procurement and Adaptation of Juvenile Turbot**

In Europe, several specialized hatcheries are engaged in the production of juvenile turbot, providing a reliable source of high-quality juveniles for aquaculture purposes. Notable examples of such hatcheries include: 1) Stolt Sea Farm (<https://www.stoltseafarm.com/> ), 2) Sea Farm (<https://www.seafarm.nl/en/> ), and 3) France Turbot (<https://www.gloriamarisgroupe.com/france-turbot-en/?lang=en> ). These facilities are capable of supplying juveniles with an average weight of approximately 10 grams, along with the necessary health certifications that ensure their compliance with international aquaculture biosecurity standards.

To minimize the costs associated with juvenile procurement, collaboration with private sector companies interested in the commercial farming of turbot may provide a mutually beneficial solution. Joint ventures or partnerships could facilitate bulk purchasing, thus lowering the overall costs per unit. Moreover, for cost-effective and efficient transport of juveniles, collaboration with enterprises that specialize in waterless transportation technology for live fish may be advantageous. This method allows for the transport of juvenile turbot via air freight, ensuring minimal stress and mortality rates during transit.

When sourcing juveniles, priority should be given to hatcheries that implement selective breeding programs aimed at enhancing desirable traits such as growth performance, disease resistance, and stress tolerance. Selecting juveniles from improved breeding lines can contribute to overall farm productivity and profitability. It is also critical to ensure that juveniles are free from undesirable physical traits such as pigmentation abnormalities (malpigmentation), morphological deformities, and any signs of external injury or damage, as these factors can negatively impact survival rates and growth efficiency in aquaculture systems.

The acclimatization of juveniles during transfer is essential, particularly if they are transported with water. If the transfer involves significant changes in temperature, the juveniles should be gradually acclimated to the temperature of the receiving environment to prevent thermal shock, which can lead to increased mortality. In preparation for transport, feeding should be suspended for at least 24 hours prior to shipment and following arrival to minimize the risk of water quality deterioration due to waste production during handling and transport.

Before introducing the juveniles into RAS, it is imperative to ensure that the system's biological filtration is fully functional. This includes verifying that the nitrifying bacteria population in the biofilters is sufficient to manage the nitrogenous waste produced by the fish. Proper operation of the biological filters is crucial for maintaining optimal water quality parameters, which directly affect fish health, growth, and survival.

For the proposed facility, an initial stock of 500 juvenile turbot, each weighing approximately 10 grams, could be procured from the aforementioned hatcheries. This stock would form the foundation of the production cycle and should be carefully managed to ensure high survival rates and growth performance during the early stages of culture.

**Turbot Grow Out**

Growth in turbot is highly dependent on a range of factors, including water temperature, larval quality, feed composition, light exposure, and other external environmental conditions. Under optimal care and management, turbot is expected to reach a body weight of from 10 grams to 500 grams within a 12-month period. However, records indicate that growth may fall below this benchmark, depending on the specific influence of these factors. At this stage, the survival rate is approximately 80%, with a feed conversion ratio (FCR) of 1.0. Turbot production is conducted in land-based systems, particularly recirculating aquaculture systems (RAS), as these systems offer precise control over environmental conditions. While sea cage systems were previously used, they were found to be unsuitable for turbot due to their benthic nature and specific rearing requirements. During the grow-out stage, stocking density for turbot weighing 500 grams is typically 20 kg/m², while for those under 500 grams, it is around 25 kg/m². Turbot primarily occupy the bottom of the tank and exhibit a tendency to stack on top of one another, which facilitates high stocking densities without compromising fish welfare. At this stage, the expected feed conversion ratio (FCR) ranges between 1.2 and 1.3, indicating efficient feed utilization under controlled conditions. Typically, turbot achieves a body weight of 2 kg after approximately two years of growth, assuming ideal farming conditions.

In the Kotor Turbot RAS, however, stocking densities have been intentionally kept lower. This conservative approach has been adopted to allow for the system’s gradual stabilization and to provide time for the training and development of skilled personnel, as turbot aquaculture is a new undertaking in this setting.

Temperature plays a pivotal role in the successful cultivation of turbot directly influencing not only growth rates but also overall metabolic processes, including feed conversion efficiency and health. Numerous studies have established that the optimal thermal range for turbot varies depending on the developmental stage and body weight of the fish. Turbot, weighing between 10 and 500 grams, exhibit the highest growth rates within a temperature range of 19–21°C. For larger individuals, exceeding 500 grams in weight, the optimal temperature range for growth shifts slightly lower, between 16–19°C.

As turbot progresses through different growth stages, their thermal requirements change accordingly. Research has shown a gradual decline in the optimal temperature for growth as body size increases. For instance, the optimal temperature is recorded at 20.8°C for 10gram fish, 19.1°C for 100gram fish, and 17.5°C for 1000gram fish. When turbot is reared outside of these specified temperature ranges, significant reductions in total weight gain are commonly observed. Suboptimal temperatures not only hinder growth but can also lead to increased stress levels and higher susceptibility to diseases, reducing survival rates and production efficiency.

Moreover, temperature has a substantial impact on the Feed Conversion Ratio (FCR), which is a key metric in aquaculture that measures the efficiency with which feed is converted into biomass. The FCR is most favourable at approximately 21°C, where feed utilization is maximized, leading to improved growth rates and reduced feed waste. Maintaining water temperature within the optimal range is thus essential for ensuring both growth optimization and cost-effective feed management in commercial turbot farming. It is recommended that water temperature be stringently regulated to remain within the upper limit of 20–21°C, while avoiding temperatures below 15–16°C. These conditions are critical for achieving the ideal balance between growth performance, FCR, and overall health of the stock. The controlled temperature range ensures that the metabolic demands of the fish are adequately met without exceeding thresholds that could lead to reduced growth efficiency or increased energy expenditure on thermoregulation. Implementing precise temperature control strategies, particularly in RAS systems, is a fundamental aspect of optimizing turbot aquaculture, contributing to both enhanced productivity and sustainability.

Marine fish, including turbot must expend significant energy on metabolic processes related to ionic and osmotic regulation, particularly when exposed to varying salinity levels. Turbot is known for its wide salinity tolerance, thriving in environments with salinity levels ranging from 10 ppt to 35 ppt. This broad adaptability allows the species to inhabit diverse marine and brackish environments, making it a suitable candidate for aquaculture across various geographic regions. However, optimal growth and feed efficiency in turbot is achieved within more specific temperature and salinity ranges. Studies have shown that the ideal temperature-salinity combination for maximizing feed consumption and feed conversion efficiency lies between 19–21°C and 19–20 ppt, respectively. Under these conditions, turbot exhibit enhanced metabolic efficiency, with energy expenditure on osmoregulation minimized, allowing more resources to be allocated toward growth and overall health. The narrow salinity range around 19–20 ppt not only supports efficient feed utilization but also ensures stable physiological conditions that are conducive to higher survival rates and faster growth.

Seawater from the Bay of Kotor exhibits salinity and temperature levels that fall within this range, making it highly suitable for turbot aquaculture. The bay’s water conditions align closely with the parameters required for promoting efficient growth and metabolic functioning in turbot, offering an excellent natural environment for aquaculture operations. The bay's stable salinity profile helps mitigate the stress that can arise from fluctuating environmental conditions, further enhancing the potential for high yields in turbot farming operations. By leveraging the favourable conditions of the Bay of Kotor, aquaculture operations can maximize the growth potential of turbot, ensuring efficient feed conversion and overall production success. Careful monitoring and management of these environmental parameters will be essential in maintaining high productivity and economic viability in turbot aquaculture.

Light is a critical environmental factor in aquaculture that affects a range of physiological processes, including growth, metabolism, and behaviour in fish. It is not only the intensity but also the photoperiod (duration of light and dark cycles) and the spectral composition (wavelength) of light that play a vital role in optimizing growth conditions for turbot. Studies have demonstrated that manipulating light conditions can significantly influence the growth performance of turbot during the rearing phase. Photoperiod refers to the ratio of light (L) to dark (D) periods in a 24-hour cycle. Research has shown that turbot can be successfully reared under various photoperiod regimes; however, the 12L:12D (12 hours of light, 12 hours of darkness) regime is associated with the highest growth rates. This balanced photoperiod appears to align with the species' natural rhythms, optimizing physiological responses such as feeding behaviours, digestion, and metabolism. In addition to photoperiod, the wavelength of light is a crucial factor influencing turbot growth. Different wavelengths of light can penetrate water to varying depths and have different effects on fish physiology. Turbot, being a benthic species, are naturally adapted to lower light intensities and specific parts of the light spectrum, particularly in the blue wavelengths. These wavelengths promote calm behaviours and reduce aggressive interactions, which may contribute to improved growth rates in aquaculture settings. While photoperiod and wavelength are key factors, light intensity also plays a crucial role in turbot growth. As a benthic species, turbot naturally inhabits low-light environments, and excessive light intensity can lead to stress, reduced feeding efficiency, and ultimately hinder growth.

Ideal light intensities for turbot rearing typically range from 50 to 200 lux, which is sufficient to stimulate feeding and growth without causing overstimulation or stress. Dissolved oxygen (DO) is a key factor in turbot aquaculture, directly influencing growth, feed utilization, and overall health. The minimum DO level for optimal growth is **6 mg/L**; below this, growth rates and metabolic efficiency decline. At **3 mg/L**, feed intake ceases entirely, while levels between **0.75–1.3 mg/L** are lethal due to hypoxia. Suboptimal DO levels significantly reduce growth and feed conversion efficiency. Oxygen-supersaturated water (147–223% saturation) does not negatively impact turbot. Studies show that feed intake, FCE, and growth remain unaffected under these conditions, making it a practical option for maintaining optimal DO in intensive aquaculture systems such as **Recirculating Aquaculture Systems**. Effective management of DO levels, particularly avoiding hypoxia while potentially using oxygen-supersaturation, is crucial for ensuring high growth rates and feed efficiency in turbot farming.

Ammonia, excreted by turbot through their gills, accumulates in the rearing water and poses a significant toxicity risk, particularly in its un-ionized form (NH₃). Ammonia toxicity can severely impair growth and metabolic function. The threshold concentration for acceptable growth in turbot over a three-month period is reported to be 5–6 mg/L of total ammonia or 0.2 mg/L of un-ionized ammonia (NH₃) at a pH of 7.5. At higher concentrations, ammonia can disrupt osmoregulation and cause physiological stress, leading to reduced growth rates and increased mortality. For optimal rearing conditions, safe total ammonia concentrations should remain below 2–3 mg/L, as levels exceeding this range have been associated with suboptimal growth and elevated stress responses in fish. The un-ionized form (NH₃) is particularly toxic, even at low concentrations, and is influenced by factors such as water temperature and pH. Proper water management, including regular monitoring of ammonia levels and maintaining appropriate pH, is therefore critical in preventing ammonia toxicity and ensuring healthy growth in turbot aquaculture.

**Nutrition and Feeding Strategies for On-Growing Turbot**

Turbot requires precise nutritional strategies to support optimal growth, health, and feed conversion efficiency. This phase is critical for achieving high growth performance and necessitates not only the selection of an appropriate feed type but also the adjustment of feed size and feeding frequency as the fish grow.

Feeds designed for turbot during the on-growing stage must meet their specific nutritional requirements, with particular attention to protein, lipids, vitamins, and minerals. As a carnivorous species, turbot demand a high-protein diet, with extruded sinking pellets being the most suitable feed form. Two of the main companies producing specialized extruded pellets for turbot are Skretting (<https://www.skretting.com/en/feed-for-aquaculture/gemma-for-turbot-18/> ) and Biomar (<https://www.biomar.com/feed-and-services/species/turbot/> ). Sinking pellets are preferred due to the benthic nature of turbot, allowing them to feed naturally at the bottom of tanks.

The size of feed pellets is critical for ensuring efficient feed intake and minimizing wastage. As turbot grow, the pellet size must be adjusted to match the increasing mouth size and ensure easy ingestion. Inappropriate feed size can lead to feed rejection or inefficient feeding, both of which can negatively affect growth and feed conversion ratios. The typical pellet size recommendations for turbot during the on-growing phase are as follows:

10-50 grams : 1.0 mm to 2.0 mm pellet size

50-200 grams : 2.0 mm to 3.5 mm pellet size

200-500 grams : 4.0 mm to 5.5 mm pellet size

500 grams and above : 6.0 mm to 10.0 mm pellet size

Larger pellets, particularly in the later stages, reduce feeding time and energy expenditure, thereby enhancing overall growth performance.

In terms of feeding frequency, juvenile turbot are typically fed multiple times per day, usually twice, to ensure continuous growth and to avoid the risk of underfeeding. As the fish reach larger sizes, the feeding frequency can be reduced to once per day, depending on the biomass and environmental conditions. Feeding frequency and rate must be carefully monitored and adjusted based on factors such as biomass, water temperature, and fish behaviour. Feeding rates should be dynamically adjusted to avoid underfeeding, which impairs growth, or overfeeding, which leads to feed wastage and deterioration of water quality. Experienced farm personnel play a critical role in feeding management. Observation of fish behaviour is essential to determine when feeding should stop—typically when the fish lose interest and stop actively consuming the feed. Uneaten feed should be minimized as it contributes to poor water quality and inefficient feed utilization, ultimately increasing production costs.

**Disease and Biosecurity**

In turbot aquaculture, the risk of disease transmission is significantly elevated due to the species' tendency to live in proximity and stack on top of one another, which increases the potential for pathogen spread and disease outbreaks. Effective disease management in turbot farming necessitates a strong focus on good husbandry practices and a proactive approach to health management. The primary goal is to minimize and mitigate the risk of disease outbreaks by adhering to biosecurity measures that address the specific challenges posed by turbot farming. Turbot is susceptible to a variety of diseases, with parasites and bacteria being the most common pathogens. Among the most prevalent parasitic diseases are Trichodiniasis, Scuticociliatosis, Microsporidiosis, and one of the most concerning parasitic infections, Enteromyxosis. On the bacterial front, diseases such as Vibriosis, Furunculosis, Flexibacteriosis, Streptococcosis, and Edwardsiellosis are frequently encountered in turbot farming systems.

The first and most effective line of defense in managing diseases and pathogens is the maintenance of optimal health conditions for the fish. Stress factors such as sudden changes in water temperature or salinity, excessive noise, and unnecessary handling should be avoided, as these can compromise the immune system of turbot and increase susceptibility to disease. Additionally, high stocking densities should be carefully managed, and handling should be minimized to reduce stress and injury.

The development of comprehensive biosecurity protocols is essential to minimize the risk of disease introduction and transmission. Key elements of biosecurity include the implementation of practical and effective legislative controls, the establishment of adequate diagnostic and detection methods for infectious diseases, the use of disinfection and pathogen eradication techniques, and ensuring the procurement of high-quality, disease-free stock. Furthermore, the adoption of best management practices (BMPs) is critical in ensuring that biosecurity measures are consistently applied across the production cycle.

A written health plan, which is updated annually and approved by an aquatic animal health specialist, is a fundamental component of biosecurity protocols. This plan should outline procedures for managing disease outbreaks, including the identification of responsible personnel, notification protocols, and steps for halting the spread of disease. Compliance with EU regulations and certification requirements often necessitates the development and implementation of such health plans.

Regular health checks and screening are essential to monitor the health of the stock and allow for rapid intervention if signs of disease begin to emerge. Some certification schemes establish specific targets for maximum average mortality rates, and maintaining detailed daily records of mortalities helps aquaculture managers predict when disease problems are likely to occur in the production cycle. One of the notable advantages of RAS technology is the enhanced level of biosecurity it provides compared to other aquaculture systems. RAS allows for precise control of environmental conditions, resulting in greater system stability and a reduced risk of disease outbreaks. However, biosecurity in RAS must be rigorously maintained, as the introduction of parasites or pathogens can be particularly challenging to manage within these systems. The presence of biological filters, which are essential for maintaining water quality, complicates the disinfection process, making pathogen control more difficult. Poorly designed RAS facilities may inadvertently create conditions conducive to disease outbreaks or the proliferation of opportunistic pathogens, exacerbating the problem.

When disease outbreaks do occur, a variety of medicines and chemical treatments are available for controlling turbot pathogens, including antibiotics. However, the overuse of antibiotics in aquaculture, as in human medicine, accelerates the development of antibiotic resistance, wherein bacteria evolve to withstand treatments that were previously effective. In Europe, the use of medicines and chemicals in fish farming is strictly regulated to minimize the impact on the farmed species, the end consumer, and the environment. Best Management Practices (BMPs), alongside codes of conduct and certification schemes, play an important role in addressing disease challenges in aquaculture.

Vaccination is another critical tool in the fight against disease in turbot farming. Turbot are routinely vaccinated against several of the most common bacterial diseases, particularly Vibriosis and Flexibacteriosis. Only veterinary medicines and chemicals approved by national authorities should be used, and they must be prescribed by an aquatic animal health specialist. The biosecurity measures at rearing facilities should include the physical isolation of the rearing tanks from other parts of the facility. Interference or contact with other areas of the farm, or the use of equipment from other sections, should be minimized or completely avoided. After each production cycle, all tanks and equipment must be thoroughly sterilized. Human contact should also be restricted, with only authorized personnel such as technicians and engineers permitted to access the facility.

The key to effective disease control and biosecurity in turbot farming lies in the consistent implementation of proactive health management practices, comprehensive biosecurity protocols, and the use of appropriate medicines and vaccines. The combination of these strategies, alongside the benefits offered by RAS technology, ensures that the risks of disease outbreaks are minimized, safeguarding both the health of the fish and the economic viability of the farming operation.

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Yapay zeka tarafından oluşturulan içerik yanlış olabilir.

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