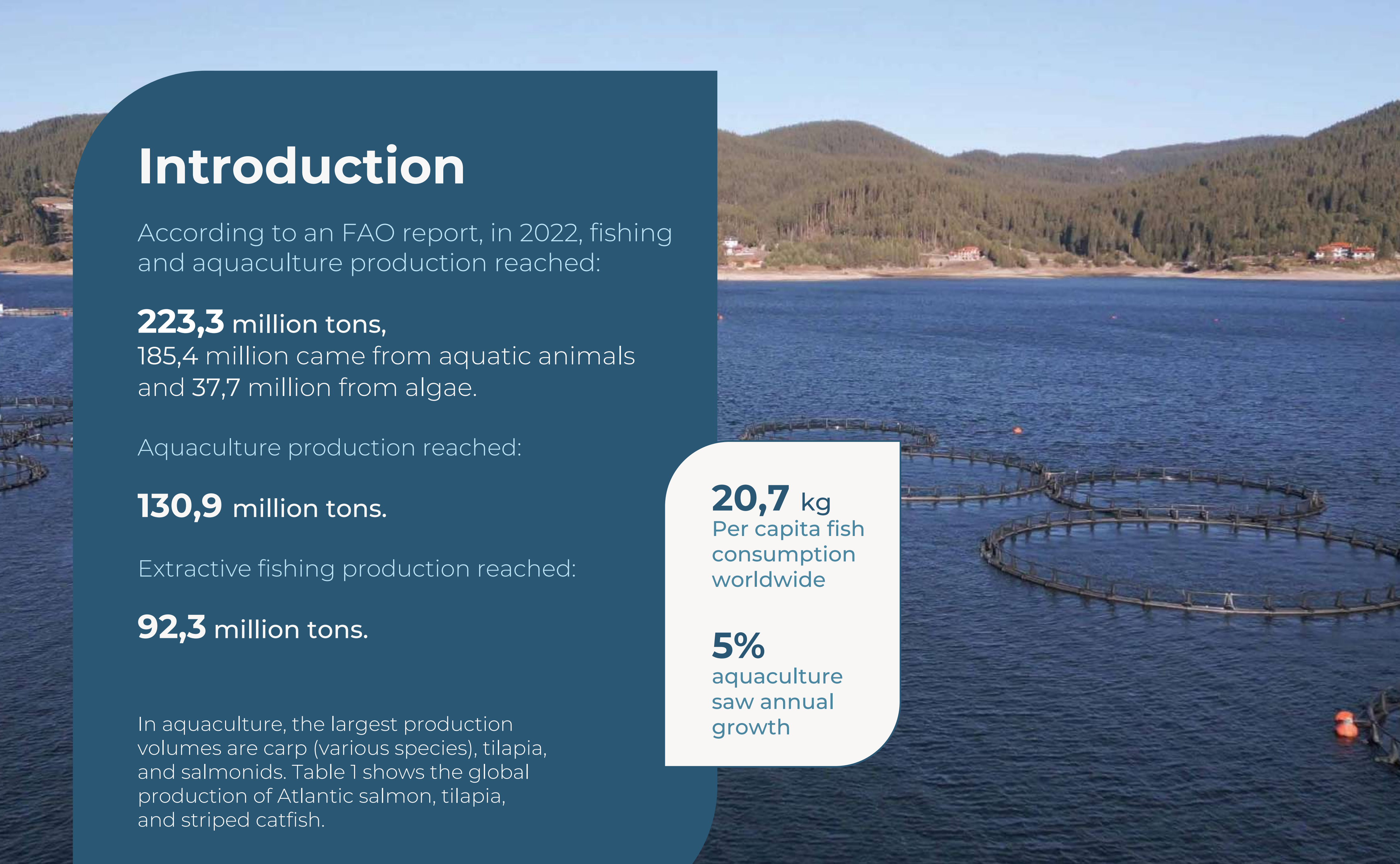
minerva foods

Good Aquaculture Practices Guide for: Atlantic Salmon, Tilapia and Striped catfish

SUMMARY



Introduction

According to an FAO report, in 2022, fishing and aquaculture production reached:

223,3 million tons,
185,4 million came from aquatic animals and 37,7 million from algae.

Aquaculture production reached:

130,9 million tons.

Extractive fishing production reached:

92,3 million tons.

In aquaculture, the largest production volumes are carp (various species), tilapia, and salmonids. Table 1 shows the global production of Atlantic salmon, tilapia, and striped catfish.

20,7 kg
Per capita fish consumption worldwide

5%
aquaculture saw annual growth

Table 1

Aquaculture production volume in metric tons (tons) worldwide

Species	2020	2021	2022	2023	2024 (estimated)	% growing (2020-2024)	Key farmers
Atlantic salmon	2.7 M	2.8M	2.8 M	2.8 M	2.9 M	+10.7%	Norway (1.53 M tons in 2023), Chile (1.0 M tons in 2023)
Tilapia	6.2 M	6.4 M	6.6 M	6.7 M	7 M	+13.4%	China (>1.6 M tons), Indonesia (>1.6 M tons), Egypt (1.1 M tons), Brazil (660,000 tons)
Striped catfish	3 M	3 M	3,1 M	3.1M	3.3 M	+11.7%	Vietnam (1.62 M tons), India (756,000 tons), Indonesia (349,000 tons)

The growing importance of fish welfare in aquaculture stems from ethical considerations and consumer market demands for higher standards of quality and sustainability. The welfare status of fish has direct implications for the production and sustainability of the aquaculture industry. Fish raised in environments with fewer stress sources experience a good welfare state and are, therefore, less susceptible to disease and the need for medication, exhibit better growth rates, yield a higher quality final product, and provide greater economic returns. Additionally, consumers in Latin America, North America, and Europe are increasingly attentive to welfare issues associated with intensive production practices and expect fish farmers to adopt measures and strategies more aligned with ensuring good animal welfare conditions. In this guide, we share science-based information and data on how to implement best practices in the production of Atlantic salmon (*Salmo salar*), tilapia (*Oreochromis sp.*), and striped catfish (*Pangasianodon hypophthalmus*). Our objective is to improve animal welfare indicators throughout the Minerva Foods supply chain and for global aquaculture.

Stress and their consequences on fish welfare in aquaculture systems

Fish, like other vertebrates, possess a central nervous system (CNS) composed of a brain and a spinal cord. Scientific studies over the last 25 years confirm that they exhibit complex cognitive abilities, such as memory, and are capable of experiencing emotions associated with pleasure and suffering, thus classifying them as sentient animals.

Animal welfare is the physical and mental state of an individual in relation to the conditions in which it lives and is slaughtered. It can range from very high to very low and/or very good to very poor, depending on the management conditions and, consequently, the level of stress to which the animals are exposed. The stress response is a natural reaction that helps fish adapt to environmental changes, improving their chances of survival. However, the more intense and prolonged the stressor—such as a sharp drop in dissolved oxygen levels in the water—the greater the difficulty for the fish to adapt. This situation directly impairs their welfare, affecting their health, development, and, in more extreme cases, leading to death.

Source of stress during fish farming

Stress increasing

- Balanced and species-appropriate feed
- Providing feed in the correct amount and on a regular basis
- Proper stocking density and good control of water parameters.

Very good animal welfare state

- Unbalanced feed
- Excess or lack of feed

Compromised growth and welfare

- High stock density
- Water quality parameters outside the tolerance range
- High load of organic matter

- Handling out of water
- Absence of preventive veterinary medicine plan
- Inadequate transportation
- Resource poor environment

Poor animal welfare state

- Frequent mixing of batches
- Competition for access to food
- Slaughter without stunning
- Presence of predators

Death

Summary of the Consequences of Stress in Production Fish

Reduced Growth Rates

Fish subjected to stressful situations degrade energy-rich compounds (e.g., carbohydrates, proteins, and fat) to cope, instead of using them for growth. This reduces growth efficiency and impairs development, as well as meat quality aspects like texture and flavor.

Immunosuppression

Stress weakens the fish's immune system, increasing the risk of disease. During vaccination or critical handling procedures, stress can reduce the effectiveness of the immune response.

Reduced Reproductive Efficiency

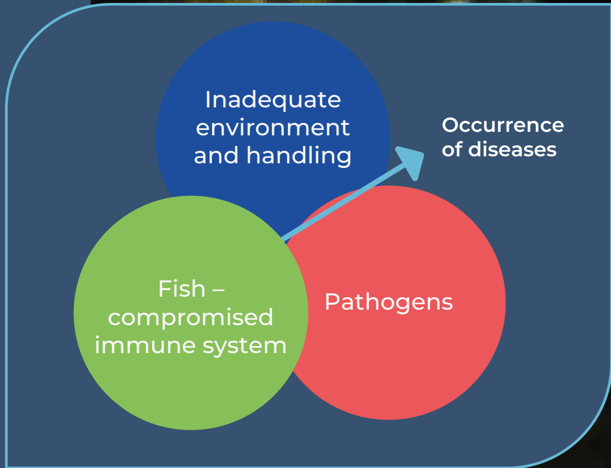
In broodstock, stress impairs the quality and/or quantity of gametes (eggs or sperm), affecting fingerling production.

Poor Pre-harvest Meat Quality

Fish subjected to stressful situations prior to harvest exhibit poorer meat quality. This is due to undesirable pH changes caused primarily by alterations in anaerobic metabolism and lactic acid formation.

Increased Mortality Rates

Fish exposed to inadequate stocking densities, poor water quality, high concentrations of organic matter, the presence of predators, improper out-of-water handling, among other factors, can experience mortality rates higher than expected.



Fish welfare assessment in aquaculture systems

Fish welfare can be measured through direct and indirect indicators, organized into 5 domains: nutrition, environment, health, behavior, and mental state. However, since assessing the mental state of animals remains complex and difficult to employ under field conditions, animal welfare assessment protocols simplify the approach into the four basic principles described in Table 2 (*Welfare Quality*®).

The indicators described are based on assessment protocols found in the scientific literature, as there is no welfare assessment protocol exclusive to fish developed by Welfare Quality.®
These indicators can be evaluated based on measurements taken from the animals themselves or from their environment.

Table 2.
Animal welfare assessment principles and criteria according to conforme Welfare Quality.®
Indicators based on the RSPCA, HFCA e Pedrazzani protocols.

Welfare principle	Welfare criterion	Welfare measure
Good feeding	• Absence of prolonged hunger	Feed conversion rate, fasting time, forms of food distribution, % of crude protein
Good housing	• Comfort around resting • Thermal comfort • Ease of movement	Stocking density, water quality parameters (e.g., pH, $\%O_2$, temperature, etc.), and animal behavioral changes (e.g., fish yapping near the water inlet)
Good health	• Absence of injuries • Absence of disease • Absence of pain induced by the handling	Presence of physical alterations, ectoparasites, use of sedatives/anesthetics in management practices, use and effectiveness of pre-slaughter stunning
Appropriate behavior	• Expression of social behaviors • Expression of other behaviors • Good human-animal relationship • Positive emotional state	Competition for access to food, time of exposure to air, feeding behavior, swimming behavior, use of environmental enrichment resources, presence of predators

Good feeding practices

Nutrition directly impacts fish welfare and can represent over 50% of production costs. Producers must ensure a diet that meets the nutritional requirements for each species and life stage, always in sufficient quantity for all fish. This prevents prolonged hunger, reduces excessive competitive/aggressive interactions, and minimizes waste. The key factors and recommended best practices for aquaculture nutrition are described below:

Nutritional requirements

Proper health and development depend in part on meeting the nutritional requirements of fish. Adequate nutrition depends on the quality of raw materials and diet formulation. There are some free websites, such as FAO to understand the nutritional requirements of each species and development category, with tables showing the main nutritional characteristics of each raw material. Additionally, other free websites such as IAFFD allow for the formulation of diets.

Websites such as IAFFD allow for the formulation of diets. From a biochemical standpoint, there are three fundamental components of cells: proteins, carbohydrates, and lipids. Proteins are the structural and functional cornerstone of biological processes in fish. They are composed of amino acids, which are divided into essential and non-essential categories. Essential amino acids cannot be synthesized by the fish and must be included in formulated diets at minimum required levels to prevent deficiencies. The absence of a single essential amino acid limits the synthesis of a specific protein and, consequently, interferes with the fish's normal physiology. Non-essential amino acids can be synthesized from other amino acids.

In the wild, fish obtain all their nutritional requirements from the diversity of food they consume. For example, in river environments, Atlantic salmon feed primarily on insects, crustaceans, and aquatic mollusks, including the larvae and nymphs of chironomids, mayflies, caddisflies, blackflies, and stoneflies. In the ocean, Atlantic salmon consume a variety of marine organisms, including crustaceans such as euphausiids (*krill*), *amphipods*, and decapods, as well as fish like *sand lance*, *smelt, alewives, herring, capelin, small mackerel,* and *small cod*.

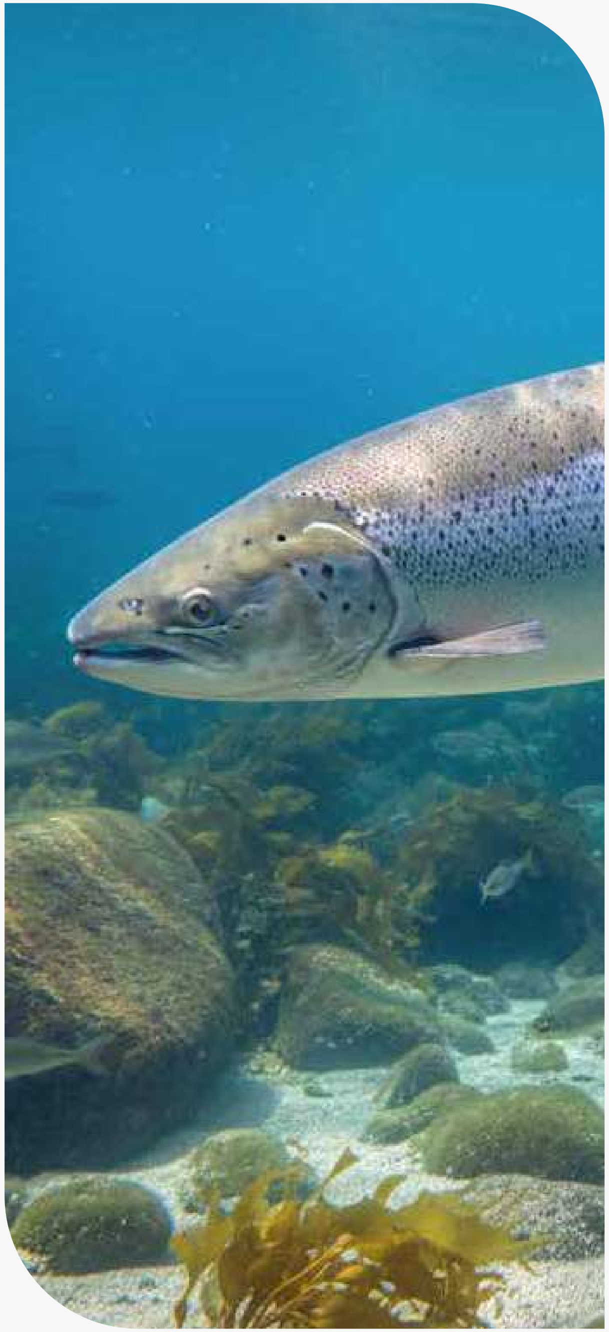
Atlantic salmon

Table 3 below presents the minimum requirements for crude protein in feed, while Table 4 outlines the minimum micronutrient requirements for each developmental stage of Atlantic salmon.

Table 3 .

Minimum requirements for crude protein, particle size, and feeding rate according to live weight and water temperature for Atlantic salmon.

Fish weight (g)	% crude protein	Feed size (mm)	Feeding rate (% body weight/day)				
			4 °C	8 °C	12 °C	16 °C	18 °C
< 0,3	50 - 55	0.3	*Ad libitum*				
0.3 – 0.8	50	0.5	2	3	4.0	4.5	4.5
0.8 – 1.5	50	0.8	1.8	2.7	3.1 – 3.5	3.9 – 4.5	3.9
1.5 - 5	50	1 – 1.2	1.8	2.7	3.5	3.9	3.4 - 3.9
5 - 10	50	1.5 – 1.8	1.6	2.1	3.1	3.4	3.4
10 -30	45 -50	2	1 – 1.4	2	2.7	3.1	3
30 – 100	48 - 50	3	1 – 1.5	1.3 – 1.9	2 – 2.2	2.7 – 2.8	2.5 – 2.6
100 - 250	46 - 48	4	1.3 – 1.5	1.9	2.2 – 2.3	2.6 - 2.8	
250 - 500	44 - 46	5	1.2- 1.3	1.7 – 1.9	1.7 - 2.3	2.3 – 2.6	
500 - 1000	44 - 46	6	0.8 - 1	1 – 1.4	1 – 1.4	1.8 -2	
1000 - 2000	42	7 – 7.5	0.5 – 0.7	0.7 - 1	0.7 - 1	1.2 -1.5	
2000 - 3000	40	9	0.5	0.7	0.7	1.1	
> 3000	40	11	0.5	0.6	0.6	1	



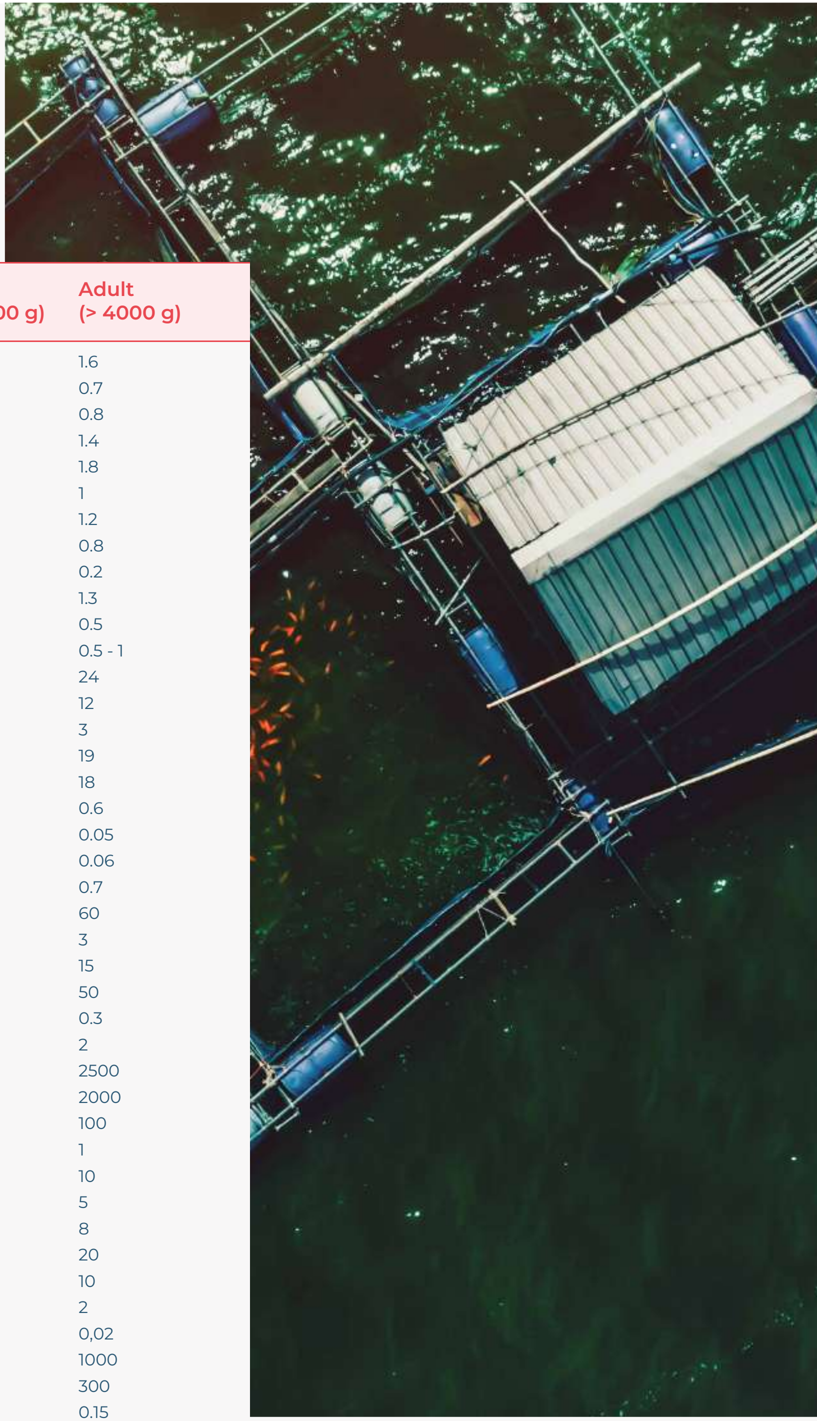
Atlantic salmon

Salmon exhibits an intolerance to high carbohydrate loads; therefore, the maximum limits are set between 10-12% of the diet. The ratios of DP (digestible protein) to DE (digestible energy) for optimal growth have been determined as follows: fry, 23 g/MJ; juveniles, 20 g/MJ; grow-out (0.2–2.5 kg), 19 g/MJ; and grow-out (2.5–4 kg), 16–17 g/MJ.

The EFA (essential fatty acid) requirement in Atlantic salmon can only be met by supplying long-chain, highly unsaturated fatty acids: eicosapentaenoic acid (EPA, 20:5n-3) and/or docosahexaenoic acid (DHA, 22:6n-3). Currently, the primary source of EPA and DHA is marine fish oil (MFO). Based on data from total body and tissue fatty acid composition, the estimated EFA requirement for salmon is 1% of the diet for combined EPA and DHA.

EFA deficiency causes reduced growth, increased mortality, and decreases concentrations of EPA and DHA in blood and liver phospholipids. Recent research has demonstrated that it is possible to replace most of the MFO with vegetable oils (VO) while maintaining growth and optimal feed utilization throughout most of the life cycle. The partial replacement of MFO in fish diets with vegetable and animal lipid sources affects tissue and cellular lipid composition.

Table 4.
Minimum requirements for amino acids, essential fatty acids, minerals, and trace elements in Atlantic salmon.



Group	Nutrients	Fry (0,3 – 1 g)	Fingerling (1 – 5 g)	Parr (5 – 30 g)	Smolt (30 – 80 g)	Grower (100 – 4000 g)	Adult (> 4000 g)
Amino acids, % min of dietary protein	AA - Arginine	2	2	2	1.6	1.6	1.6
	Histidine	0.7	0.7	0.7	0.8	0.7	0.7
	Isoleucine	0.8	0.8	0.8	0.8	0.8	0.8
	Leucine	1.4	1.4	1.4	1.4	1.4	1.4
	Lysine	2	1.8	1.8	1.8	1.8	1.8
	Methionine	1.1	1	1	1	1	1
	Phenylalanine	1.2	1.2	1.2	1.2	1.2	1.2
	Threonine	0.8	0.8	0.8	0.8	0.8	0.8
	Tryptophan	0.2	0.2	0.2	0.2	0.2	0.2
	Valine	1.3	1.3	1.3	1.3	1.3	1.3
Essential fatty acids, % min	20:5n-3	0.5	0.5	0.5	0.5	0.5	0.5
	22:6n-3	0.5 - 1	0.5 - 1	0.5 - 1	0.5 - 1	0.5 - 1	0.5 - 1
Crude lipid, % min		16 – 18	20	20	20 -24	20-30	24
Carbohydrate % max		10	10	12	12	12	12
Crude fibre, % max		2	3	3	3	3	3
Digestible energy, min kJ/g		19	19	19	20	20	19
Protein/energy ratio, mg/kJ		23 – 24	22 – 23	21 – 22	20 - 21	17 – 18	18
Minerals (%)	Fósforo, min	0.7	0.7	0.6	0.6	0.6	0.6
	Magnesium, min	0.05	0.05	0.05	0.05		0.05
	Sodium, min	0.06	0.06	0.06	0.06		0.06
	Potassium	0.7	0.7	0.7	0.7	0.7	0.7
Microelements, min mg/kg dry diet	Iron	60	60	60	60	60	60
	Cooper	3	3	3	3	3	3
	Manganese	15	15	15	15	15	15
	Zinc	50	50	50	50	50	50
	Selenium	0.3	0.3	0.3	0.3	0.3	0.3
	Iodine	1	1	1	2		2
Vitamins, min IU/kg	Vit A	2500	2500	2500	2500	2500	2500
	Vit D	2400	2400	2400	2000	2000	2000
Vitamins, min mg/kg	Vit E	50 - 100	50 - 100	50 - 100	50 – 100	100	100
	Vit K	1	1	1	1	1	1
	Thiamine	10	10	10	10	10	10
	Riboflavine	5	5	5	5	5	5
	Pyridoxine	8	8	8	6	6	8
	Pantothenic acid	20	20	20	20	20	20
	Niacin	10	10	10	10	10	10
	Folic acid	2	2	2	2	2	2
	Vit B12	0.02	0.02	0.02	0.02	0,02	0,02
	Choline	800	800	1000	1000	1000	1000
	Inositol	300	300	300	300	300	300
	Biotin	0.]15	0.15	0.15	0.15	0.15	0.15
	Vit C	50	50	50	50	50	50

In salmon, signs of mineral and other nutrient deficiencies include:

- reduced bone mineralization
- anorexia (potassium)
- lens cataracts (zinc)
- skeletal deformities (phosphorus, magnesium, zinc)
- fin erosion (copper, zinc)
- nephrocalcinosis (magnesium and selenium toxicity)
- tetany (potassium)
- thyroid hyperplasia (iodine)
- muscular dystrophy (selenium)
- microcytic hypochromic anemia (iron)

Tilapia

For tilapia, the requirements for crude protein, pellet type, pellet size, feeding rate relative to body weight, and the number of daily feedings can be found in Table 5. Although there is a lack of information on the exact quantitative nutrient requirements for other life stages of tilapia, it can be expected that larval and early juvenile fish (0.02-10.0 g) will require a diet higher in protein, lipids, vitamins, and minerals, and lower in carbohydrates. Juvenile fish (10-25 g) require more energy from lipids and carbohydrates for metabolism and a lower proportion of protein for growth. Larger fish (>25.0 g) require even less dietary protein for growth and can utilize even higher levels of carbohydrates as an energy source.

Table 5.

Minimum requirements for crude protein, particle size, feeding rate by body weight, and feeding frequency for tilapia.

Life stage	Fish size (g)	Feed crude protein %	Feed type	Feed size (mm)	Feeding rate (% body weight)	Minimal Feeding frequency (N°/day)
Larvae	0 - 1	45 - 50	Power	0.2 - 1	15 -30	*Ad libitum*
Fingerlings	1 - 5	40	Crumble	1 – 1.5	5- 15	> 3
	5 -20	35-40	Floating	1.5 – 2	4 – 8	> 3
Juveniles	20 - 100	30 -36	Floating/ sinking pellet	2	3 – 6	> 3
Grow-out	> 100	28-32	Floating/ sinking pellet	3 - 4	2	> 2
Broodstock	> 150	40 - 45	Floating/ sinking pellet	4	2	> 2

Table 6.
Minimum requirements for amino acids, essential fatty acids, minerals, and trace elements for tilapia.

Group	Nutrients	% min of dietary protein
	AA - Arginine	1.18
	Histidine	0.48
	Isoleucine	0.87
	Leucine	0.95
Amino acids	Lysine	1.43
	Methionine	0.75
	Phenylalanine	1.05
	Threonine	1.05
	Tryptophan	0.28
	Valine	0.78
Essential fatty acids, % min	18:2n-6	0.5 – 1.0
	22:4n-6	1.0
Carbohydrate % max		40
Crude fibre, % max		8 -10
Protein-to-energy ratio, mg/kJ		110 -120
Minerals (%)	Cálcio, max	0.7
	Phosphorus, min	0.8 – 1.0
	Magnesium, min	0.06 – 0.08
	Potassium	0.21 – 0.33
Microelements, min mg/kg dry diet	Iron	60
	Cooper	2-3
	Manganese	12
	Zinc	30 -79
	Selenium	0.4
	Chromium	139.6
Vitamins, min IU/kg	Vit A	5,000
	Vit D	375
Vitamins, min mg/kg	Vit E	50 – 100
	Vit K	4.4
	Thiamine	4
	Riboflavin	5 – 6
	Pyridoxine	1.7 – 9.5
	Pantothenic acid	10
	Niacin	26 – 121
	Folic acid	0.5
	Vit B12	Not required
	Choline	1000
	Inositol	400
	Biotin	0.06
	Vit C	420

Striped catfish

In general, studies on the nutritional requirements of striped catfish are limited and highly fragmented. The most recent research has focused on protein, lipid, and carbohydrate requirements, with studies on feed ingredient utilization (digestibility) and amino acid needs being conducted primarily on fingerlings. The crude protein requirement for maximum growth is 38.5% for striped catfish of approximately 2 g, and the adequate protein level for optimal growth is 29% to 33%. Larger fingerlings (5–6 g) require a diet with less protein, approximately 32.2%, with an energy content of 20 KJ/g. An inverse relationship exists between fish size and protein requirement.

According to Glencross et al. (2010), fish of 5 to 50 g require 34 to 36% dietary protein, fish of 50 to 100 g require 32 to 34%, fish of 100 to 300 g require 30 to 32%, fish of 300 to 500 g require 28 to 30%, and fish over 500 g require 24 to 26% protein.

Table 7.
Nutritional requirements for striped catfish.

Group	Nutrients	% min of dietary protein
Amino acids	Lysine	5.35
	Methionine	2.27
Crude protein, % min		38.5
Crude lipid, % min		6.5
Carbohydrate. % max		47
Crude fibre, % max		2
Gross energy, min kJ/g		21

Table 8.

Feed specifications for striped catfish, including pellet size, feeding rate, and number of feedings per day.

Life stage	Fish size (g)	Days post-hatch	Feed type	Feed size (mm)	Feeding rate (% body weight)	Minimal Feeding frequency (N°/day)
Larvae	0.01	1				*Ad libitum*
	0.5	2 -15				*Ad libitum*
Fingerlings	30	16 –30	Crumble/pellet	< 0.7	8 -10	> 4
	31 - 100	31 - 90	Pellet	1.2 – 2	6 – 8	> 3
Juveniles	101 - 800	91 – 150	Pellet	3	2 – 5	> 2
Grow-out	801 - 1220	151 – 330	Pellet	5	1.5 – 3.5	> 2
Broodstock	> 1220	> 330	Pellet	8	1.5 – 3.5	> 2

Feed Storage and Biosecurity

Feed must be stored in spaces specifically designated for this purpose, in a dry location protected from light, with controlled access to prevent entry by other animals such as birds and rodents. Feed bags must be placed on pallets and not directly on the floor, and kept away from walls. In the case of manual feeding, the husbandry staff must have separate utensils for each room and/or fish category (larvae, fingerlings, grow-out). Utensils must never be shared between different fish groups, as this represents a risk for pathogen dissemination.

Store feed in enclosed, dry areas protected from pests. Place feed bags on pallets and away from walls

Fasting Periods to be Implemented

Controlling fasting time is essential to avoid prolonged hunger states prior to handling, transport, and slaughter. Furthermore, in cases where weather conditions prevent the feeding of fish in open water, contingency protocols for providing feed to the fish must be in place.

Prolonged fasting, beyond inducing hunger, triggers protein catabolism to meet metabolic demands. This period is more critical for tropical species like tilapia and striped catfish, which have a faster metabolism, in contrast to cold-water fish like Atlantic salmon. Pre-slaughter, prolonged fasting can alter the composition of intramuscular fat, leading to undesirable sensory changes in the final product.

Atlantic salmon:

Pre-handling: 48 hours (freshwater phase).
Pre-handling: 72 hours (seawater phase).
Pre-slaughter: up to 7 days, or 70 degree-days

Tilapia:

Pre-handling: up to 24 hours.
Pre-slaughter: up to 48 hours

Striped catfish:

Pre-handling: up to 24 hours.
Pre-slaughter: up to 48 hours

Feed Distribution Methods and Feeding Frequency

Adequate feed distribution depends on the time the feed should be consumed by the fish, the surface area of the water, the particle size, and the feed characteristics.

Atlantic salmon:

El alimento es peletizado y se hunde al entrar en contacto con el agua; el salmón consume el alimento en la columna de agua.

Tilapia:

The feed undergoes an extrusion process that allows the particles to float on the water's surface; therefore, tilapia rise to the surface to consume the feed.

Striped catfish:

the feed must be pelleted and extruded to achieve varying densities, allowing the particle to sink at different rates. This ensures feed consumption occurs at the water surface, within the water column, and at the bottom of the tank.

Water quality conditions determine feeding practices. Before providing feed, check the water's temperature, dissolved oxygen (DO), and ammonia (NH_3) levels. The feeding regimen should be adjusted according to the water temperature for tilapia and striped catfish.

It is recommended to avoid feeding at production sites where the water temperature falls below 15 °C or rises above 32 °C, as feeding tilapia or striped catfish is not recommended at these temperatures.

Monitor water quality conditions. Dissolved oxygen values below 4 mg/L or un-ionized ammonia (NH_3) values above 0.1 mg/L can severely impair feed conversion. In nature, salmon, tilapia, and pangasius feed multiple times per day depending on food availability, with the first peak of activity in the morning and late afternoon. In aquaculture, salmon are fed regularly throughout the day in small portions, including early evening. Tilapia are fish with diurnal feeding habits, making feeding suitable during morning and afternoon periods. In autumn and winter, it is most appropriate to feed during the warmest periods (afternoon).

Check the color, odor, and texture of the feed before providing it to the fish; never provide feed with an altered appearance or odor

Verify that the feed particle size is compatible with the size and category of each species to be fed.

Distribute the feed over more than 70% of the water surface area; this ensures all fish have access to the feed, reducing aggressive interactions.

Avoid feeding tilapia and striped catfish during the early morning hours between 5-8 AM due to low dissolved oxygen levels.

Feed salmon small portions throughout the day, monitoring fish behavior using underwater cameras.

After verifying dissolved oxygen levels, confirm the "behavioral feeding" of the fish at the start of each feeding to avoid food waste.

Record the amount of feed provided daily and monitor fish growth by performing biometrics at least every 3 weeks on a representative sample.

Calculate the feed conversion ratio (FCR)

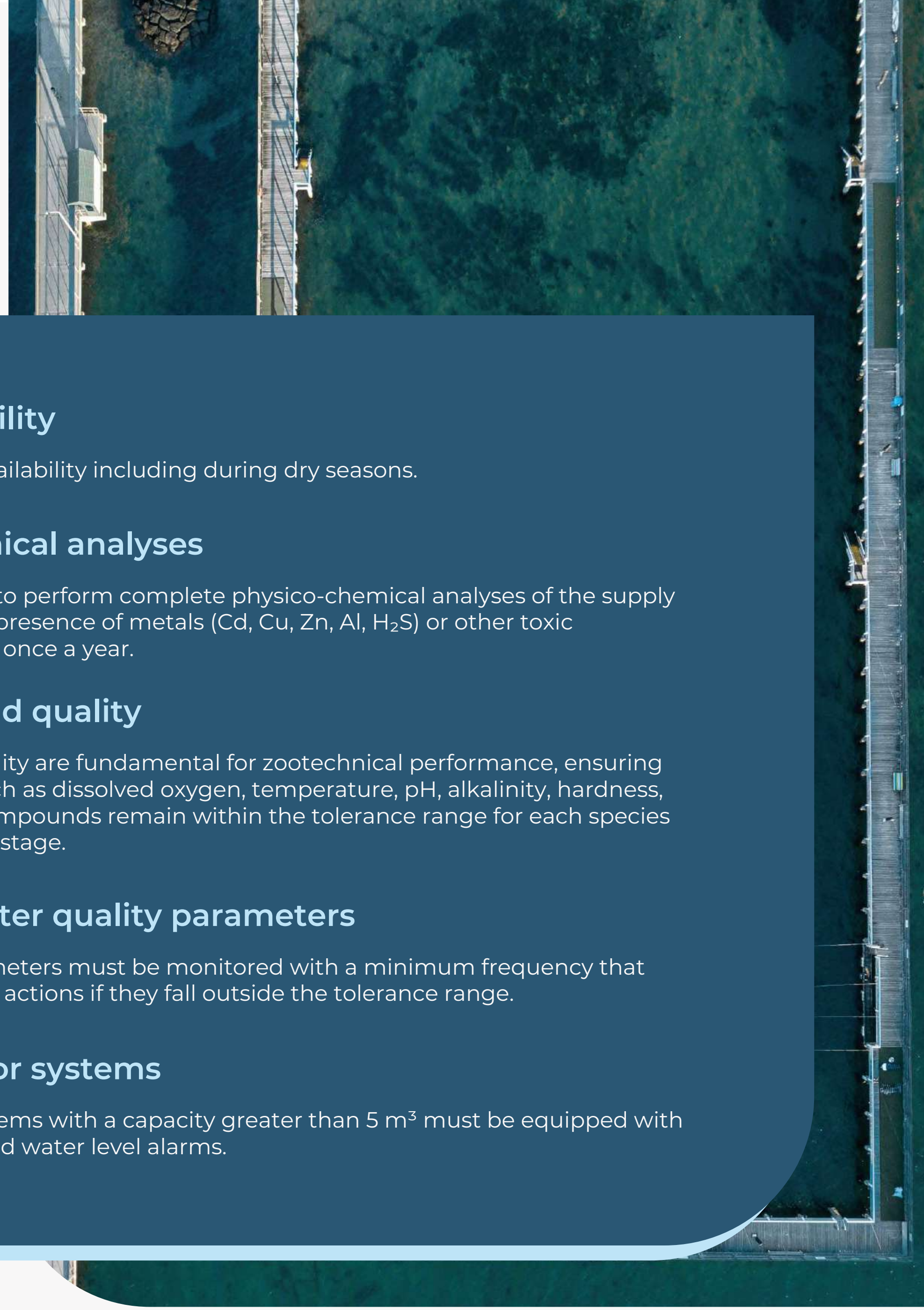
Good housing practices

Water Quality

Farm-raised fish are housed in confinement conditions; in this sense, producers are responsible for providing a suitable aquatic environment that allows for the proper development of each species, permits freedom of movement, and maintains water quality within the tolerance range for each species.

Net-pens must be securely anchored to the water body's bottom to ensure they can withstand the climatic conditions of the production site. Prior planning is essential for selecting a location that meets maintenance conditions and has a good quality water supply.

In the case of earthen pond systems or IPRS, soil conditions also determine the success of the fish farm. Avoid highly porous soils and those with extremely acidic or alkaline pH.



Water availability

Guarantee water availability including during dry seasons.

Physico-chemical analyses

It is recommended to perform complete physico-chemical analyses of the supply water to assess the presence of metals (Cd, Cu, Zn, Al, H_2S) or other toxic compounds at least once a year.

Water flow and quality

Water flow and quality are fundamental for zootechnical performance, ensuring that parameters such as dissolved oxygen, temperature, pH, alkalinity, hardness, and nitrogenous compounds remain within the tolerance range for each species and developmental stage.

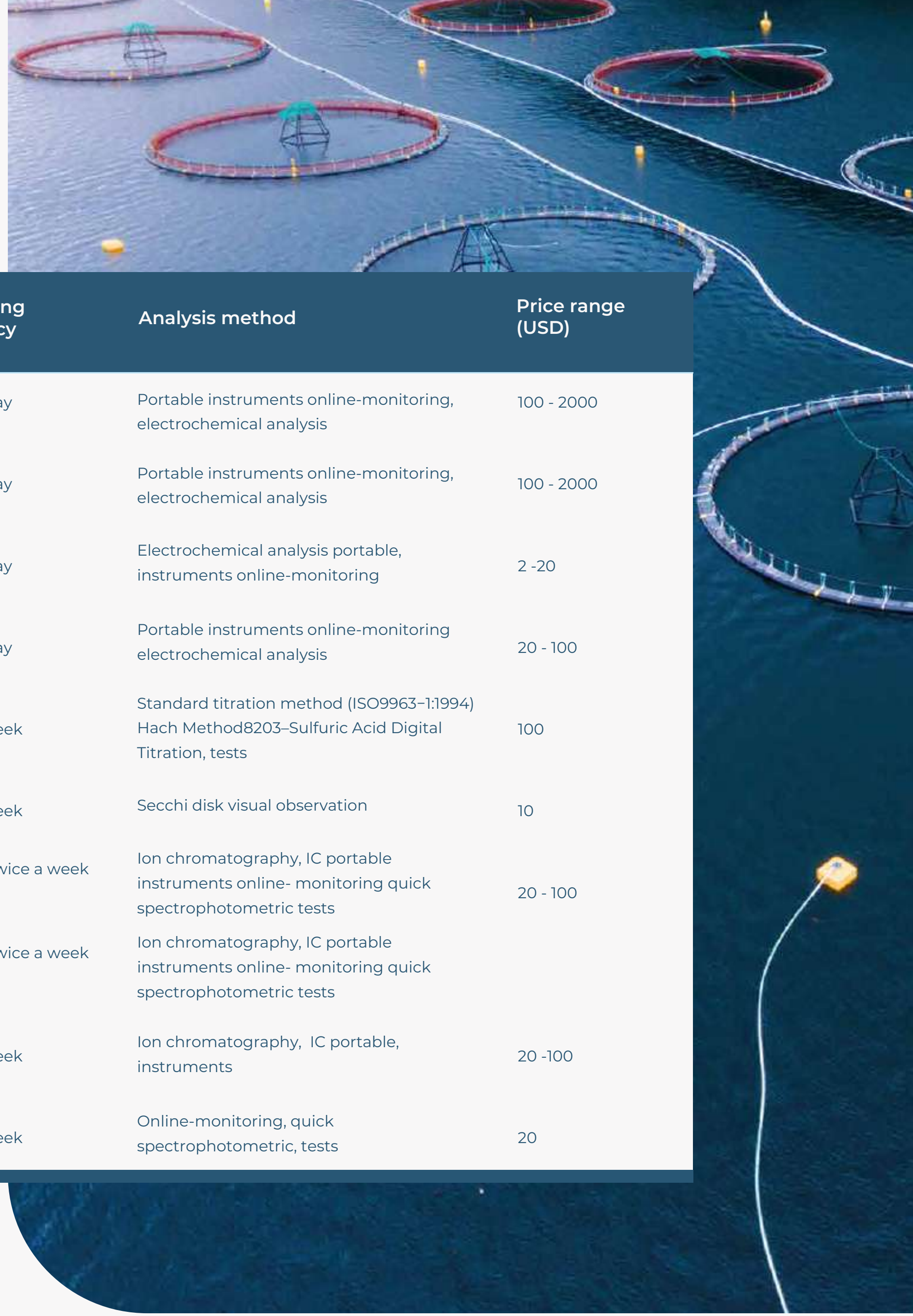
Monitored water quality parameters

Water quality parameters must be monitored with a minimum frequency that allows for corrective actions if they fall outside the tolerance range.

Tanks in indoor systems

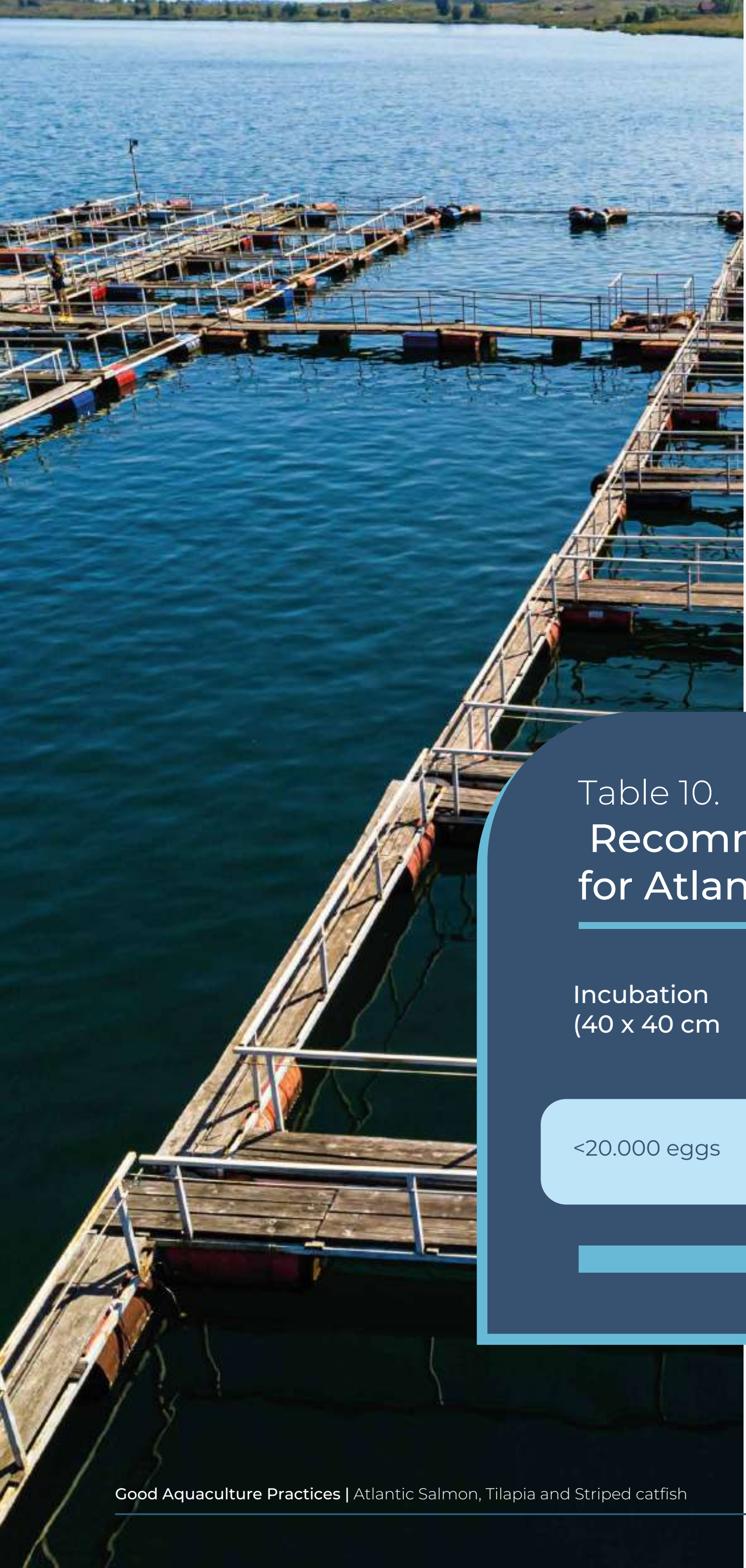
Tanks in indoor systems with a capacity greater than 5 m^3 must be equipped with dissolved oxygen and water level alarms.

Table 9.
Recommended Key Water Quality Parameters for Atlantic Salmon, Tilapia, and Striped catfish.



Parameter	Atlantic salmon – freshwater phase	Atlantic salmon – seawater phase	Tilapia	Striped catfish	Monitoring frequency	Analysis method	Price range (USD)
OD (mg/L)	7	7	4	2	Twice a day	Portable instruments online-monitoring, electrochemical analysis	100 - 2000
OD saturación (%)	70 - 110	70 - 110	>40% - < 110%	>40% - < 110%	Twice a day	Portable instruments online-monitoring, electrochemical analysis	100 - 2000
T °C	<15	5-15	21 - 35	28-32	Twice a day	Electrochemical analysis portable, instruments online-monitoring	2 -20
pH	5.5 – 8.0	5.5 – 8.0	6.0 – 8.5	6.8 – 8.]0	Twice a day	Portable instruments online-monitoring electrochemical analysis	20 - 100
Alkalinity (mg/L $CaCO_3$)	50-300	-	30 - 100		Once a week	Standard titration method (ISO9963–1:1994) Hach Method8203–Sulfuric Acid Digital Titration, tests	100
Transparency (cm)		-	30-45		Once a week	Secchi disk visual observation	10
Unionized ammonia (mg/L NH_3)	<0.025 *	-	<0.05	<0.05	Once or twice a week	Ion chromatography, IC portable instruments online- monitoring quick spectrophotometric tests	20 - 100
Nitrite (mg/L NO_2)	150 *	-	<0.5	<0.1	Once or twice a week	Ion chromatography, IC portable instruments online- monitoring quick spectrophotometric tests	
Salinity (ppt parts per thousand)	Smoltification	15-35	<10 ppt	<13 ppt	Once a week	Ion chromatography, IC portable, instruments	20 -100
CO_2 (mg/L)	<20*				Once a week	Online-monitoring, quick spectrophotometric, tests	20

* Not applicable to flow-through systems
- Not applicable to offshore net cage systems.
Blank spaces indicate insufficient information.



Stocking densities

Atlantic salmon

Stocking density must be appropriate for each species and developmental stage, thereby providing adequate space for each individual. Increased density can lead to behavioral problems, acting as a stressor that worsens the degree of fish welfare. Table 10 shows recommended maximum stocking density values for Atlantic salmon. Source: HFAC para salmón del atlántico (2025).

Table 10.
Recommended maximum stocking densities for Atlantic salmon.

Incubation (40 x 40 cm	Fry (First feeding/m^2)	Until 1 g	1 - 5 g	5 - 30 g	30 – 50 g	> 50 until 130 g	Smolt until slaughter
<20.000 eggs	<12.000	< 10 kg/m^3	< 25 kg/m^3	< 35 kg/m^3	< 50 kg/m^3	< 60 kg/m^3	< 22 kg/m^3

Tilapia and Striped catfish

For tilapia, the maximum densities during the incubation and fingerling stages depend on the maintenance of water quality. For the grow-out phase, where fish larger than 50 g are stocked, the maximum recommended densities are according to the production system (Table 11, source: ICA, 2023).

Table 11.
Recommended maximum stocking densities for tilapia.

Ground pond	IPRS (Intensive Pond Raceway System)	Net-cage	Geomembrane -Lined Tanks	RAS (Recirculating Aquaculture System)
2-9 kg/m^2	< 15 kg/m^3	-	9 kg/m^3	10 kg/m^3

These stocking densities for tilapia are still under development and study; research must ensure that such densities meet minimum animal welfare criteria.

Densities Catfish

For striped catfish, maximum stocking densities have not been officially established. Recent studies indicate better zootechnical performance and lower stress levels in juveniles stocked at 60 fish/m³, with an initial average weight of 17.5 ± 0.2 g and a final average weight of 180 g after 90 days in a closed system with 30% water exchange and siphon removal of feces every two days.

A laboratory study estimated ideal densities for pangasius (5.5 g) at 10 fish/150 L, or 66 fish/m³ over a 60-day production period, including daily siphon removal of feces and water replenishment. Water quality conditions were maintained at 27-29 °C temperature, dissolved oxygen (DO) at 5.6-6.8 mg/L, pH 7.3-7.7, and total ammonia at 0.7-1.4 mg/L.

A laboratory trial using Biofloc Technology (BFT) demonstrated that pangasius (7.34 ± 0.06 g) cultured for 90 days at lower densities (150 fish/m³), compared to higher densities (180, 210, 240, or 270 fish/m³), exhibited higher weight gain, improved feed conversion ratio, lower levels of hepatic enzymes, better control of water quality parameters, and higher survival rates after challenge with *Aeromonas hydrophila*.

A study under culture conditions in Bangladesh (a tropical country) showed that pangasius housed in net cages (6 m x 3 m x 2.1 m) with an initial weight of 50 g and a final weight of 649 g, after 90 days of culture, a density of 19 fish/m³ performed better compared to higher densities (22 or 25 fish/m³) in terms of daily weight gain, feed conversion ratio, and survival rate. Water quality conditions were recorded as temperature 28.59 ± 0.38 °C, dissolved oxygen 5.06 ± 0.06 mg/L, pH 7.02 ± 0.06, ammonia 0.115 ± 0.0048 mg/L, and transparency 35.85 ± 0.26 cm.

Intensive systems such as IPRS or RAS, which constantly renew water, lead to the constant removal of toxic products that accumulate in the water, but also eliminate chemical communication substances between fish. Therefore, the constant flushing of these substances causes additional stress, particularly in species with a developed sense of smell, such as tilapia and striped catfish

In this scenario, fish must signal their social status physically through aggressive interactions, a problematic aspect for highly territorial species like tilapia. Furthermore, these production systems practice stocking fish of the same size, which further increases aggressive interactions.

Predator and Escape Control

Likewise, the control of aerial, aquatic, and terrestrial predators using screens or nets is fundamental to prevent additional stress in fish. Predator control must follow the environmental and animal protection regulations according to each country, but the use of lethal methods for their control is not recommended.
Aquatic production systems must possess physical barriers that prevent the entry of aquatic, terrestrial, and aerial predators. The use of screens at the water supply source is essential to prevent the presence of other fish species.

Similarly, to meet sustainability criteria, production systems must be designed to prevent fish escapes. The regular verification of nets and screens to prevent fish from escaping must be incorporated into the management routine of production systems. In the case of earthen ponds, the use of sedimentation ponds, in addition to systems for removing nitrogenous compounds from the water, also serves as a filter to capture fish that have escaped from the ponds.

Good health and behavioral practices

Health is a fundamental pillar for ensuring proper zootechnical development. Therefore, the implementation of good sanitary practices is essential in aquaculture. Good health practices should include a veterinary plan for preventive medicine, with biosecurity measures; out-of-water handling to reduce stress; selection of quality fingerlings; fish reception and transport; water quality control; fish euthanasia; and contingency plans. Early recognition of signs of disease in fish is essential to reduce the pathogen load, as well as to apply euthanasia to moribund fish

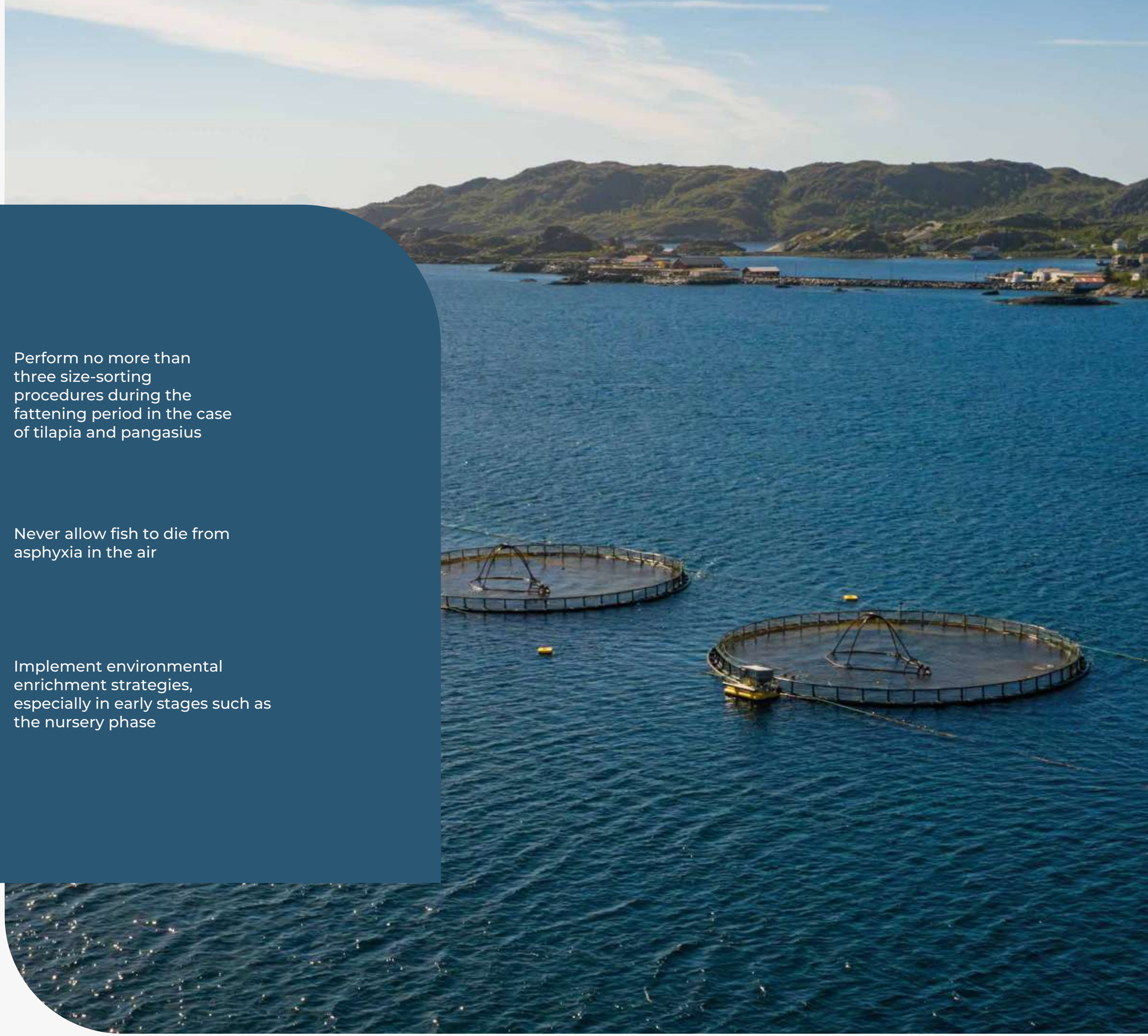
Environmental enrichment helps stimulate natural behaviors, reducing stress. Together, these measures improve animal welfare, increase productivity, and reduce economic losses, benefiting the entire production chain. Some basic biosecurity measures in aquaculture include:

- Implement a fish lot identification system.
- A health plan implemented by a veterinarian
- Record of the health status of the fish
- Log of vehicle and personnel entry into production facilities
- Record of cleaning and disinfection activities
- Record of clinical findings in mortality, specifying the causes of death
- Record of treatments administered
- Health record for new fish entering the system, including a quarantine period
- Record of pest control and feed storage
- Record of water quality control

Good health and behavioral practices

Handling fish out of water constitutes one of the main stressors in the routine of fish farming. In this sense, it is recommended to draft a handling protocol for situations where fish must be kept out of the water for more than 30 seconds, such as during biometrics, size grading, or vaccinations. The use of anesthetics prior to vaccination is essential to reduce post-vaccination mortality rates resulting from traumatic injuries during handling and to ensure the expected vaccine response is achieved. Post-vaccination, fish must be kept in a resting period for a minimum of two weeks before being transferred or transported. The general recommendations for good health and behavioral practices are found below:

- Monitor fish behavior daily, at a minimum twice per day during feeding times.
- Dispose of dead fish carcasses properly, following local environmental regulations.
- Prevent wildlife from accessing mortalities
- Water sharing between ponds leads to a decline in water quality and facilitates the spread of pathogens.
- Disinfect utensils and equipment; rinse them thoroughly with running water before each use.
- Establish sanitation barriers for the disinfection of vehicles and personnel.
- Identify and remove dead fish to prevent the spread of pathogens to healthy fish and to avoid worsening water quality.
- Identify and remove moribund fish and perform a recommended euthanasia procedure appropriate for the fish size, in accordance with the veterinarian's recommendations.
- Ensure each tank or earthen pond has an independent water inlet and outlet, without water sharing between ponds.
- Avoid sharing utensils and equipment between ponds or tanks experiencing a health issue or where a disease is suspected.
- Perform a general cleaning and disinfection of all production facilities before starting a new production cycle.
- Require that your fingerling supplier provides healthy fish and follows local legislation regarding mandatory diagnostic tests.

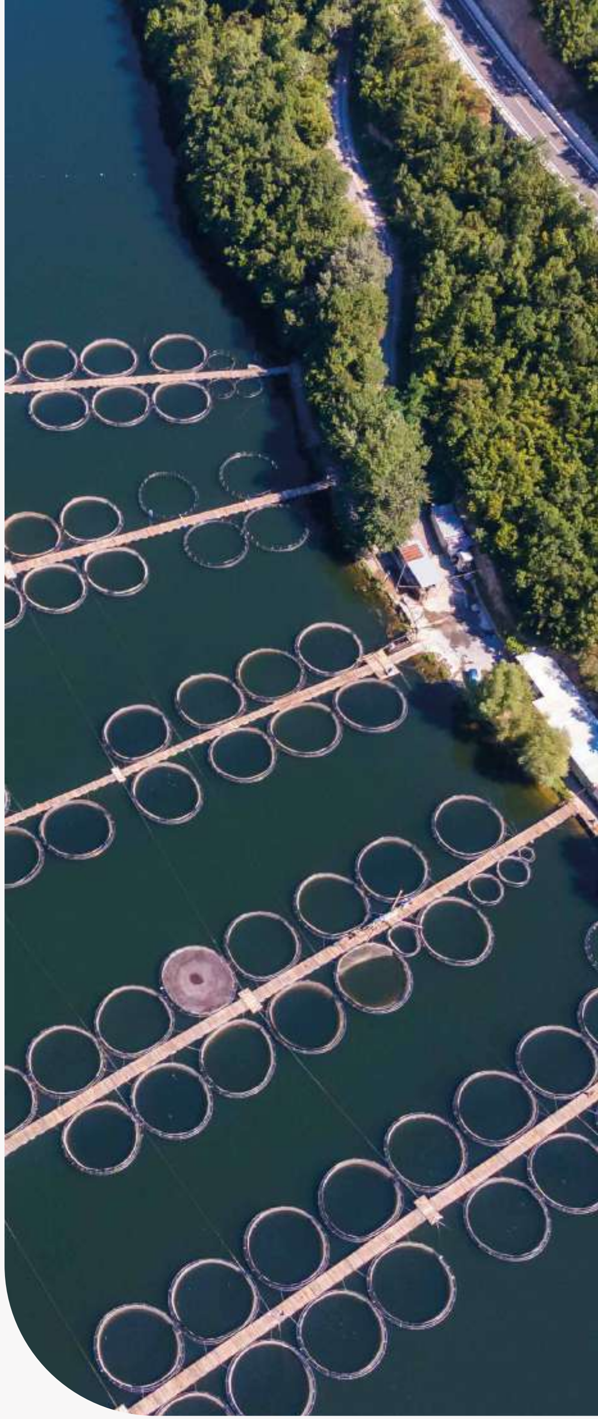


- Only implement treatments under the supervision and guidance of a veterinarian
- Carry out handling procedures under sedation or anesthesia when air exposure exceeds 30 seconds
- Establish euthanasia protocols for moribund or severely injured fish
- Perform no more than three size-sorting procedures during the fattening period in the case of tilapia and pangasius
- Never allow fish to die from asphyxia in the air
- Implement environmental enrichment strategies, especially in early stages such as the nursery phase

Good health and behavioral practices

The presence of females in tilapia grow-out batches (>150 g) triggers a cascade of zootechnical dysfunctions: males initiate territorial reproductive behavior by excavating nests and competing for areas at the bottom of the ponds. These aggressive interactions generate chronic stress, with a 30-50% reduction in feed intake. Aggressive interactions cause skin lesions that serve as entry points for pathogens.

Consequently, a 15-20% decrease in growth rate and greater size heterogeneity are observed, compromising feed efficiency. In this context, during the larval stage, tilapia receive masculinizing hormone in the process known as sex reversal or masculinization. From an animal welfare perspective, to avoid the presence of females, the reversal rate must guarantee a minimum of 99% males.



Environmental Enrichment

The implementation of environmental enrichment in aquaculture emerges as a tool to promote animal welfare and, concurrently, enhance production efficiency. By introducing elements that mimic the complexity of the natural habitat – such as physical underwater structures, variable water currents, or foraging opportunities – it is possible to stimulate natural behaviors and significantly reduce chronic stress levels in fish. This positive stimulation has direct and measurable implications: the reduction of stress is intrinsically linked to a more robust immune system, which translates to lower disease incidence and reduced medication use. In the productive sphere, less stressed animals channel energy that would be spent on stress responses into anabolic processes, resulting in better growth rates and feed conversion. Additionally, the reduction of stereotypic behaviors and aggressive interactions (such as fin biting) improves physical integrity, reflecting in a superior quality final product.

Practical examples of environmental enrichment in aquaculture.

Structural - substract

Substrate is particularly important for all species during the reproduction period. This substrate occurs naturally in earthen ponds for tilapia and pangasius. This type of enrichment can be utilized in RAS (Recirculating Aquaculture Systems) for Atlantic salmon.
Additional information: Janhunenl et al. (2021)

Structural – Shelter and hiding structures

The use of shelter structures for fish, such as PVC pipes cut in half, represents a simple and effective method to implement environmental enrichment in tanks. Additionally, structures that mimic aquatic vegetation can be utilized to enhance habitat complexity.
Additional information: Neto et al. (2025), Prentice et al. (2025), Oliveira et al. (2024)

Sensorial – music

The use of classical music has demonstrated benefits under laboratory conditions and shows potential for application in commercial culture systems.

Sensorial – water current

The opportunity for fish to swim against or with a water current is an easily implemented enrichment alternative in RAS (Recirculating Aquaculture Systems) or in systems where the natural water current already serves this function.

Good practices in the transport of smolts or fingerlings

Inappropriate transport consequences

The transport of smolts in the case of Atlantic salmon, or fingerlings in the case of tilapia or striped catfish fingerlings is a fundamental part of the production process.

Fish mortality post-transport is the primary consequence of inadequate transport. Furthermore, the stress on surviving fish will have productive and health consequences, as they may not reach their productive potential and become susceptible to diseases.

Risk factors for inadequate transport are related to operational management, the health status of the animals, poor water quality, long transport times, and abrupt temperature changes.

Good practices in the transport of smolts or fingerlings

Prior plannig

Before the procedures, plan the transport, including the route, necessary materials, and mandatory documents according to local legislation, and estimate densities in g/L.

During planning, the feeding of the fingerlings to be transported must also be suspended 24 hours prior to handling, with a maximum fasting time of 48 hours considered in the case of smolts.

On the day of loading, identify and separate sick fish, those with altered swimming behavior, or moribund fish. Do not crowd the fish for more than two hours.

For instructional purposes, follow the planning checklist below

1 Transport planning

Have all transport points been planned? Include route, vehicle, weather conditions, emergency plans, condition and cleanliness of utensils, staff training, and mandatory documents.

2 Density calculation

Have the densities been calculated in kg/m³ or g/L according to the specificities of the route?

3 Responsibilities and operation

Are all parties involved in the process—supplier, transporter, receiver—aware of their responsibilities and the operation?

4 Cleaning and disinfection

Are the materials, utensils, and vehicles properly cleaned and disinfected?

5 Equipment and sensors

Are all equipment and sensors properly calibrated?

6 Water quality

Is the transport water properly prepared?

7 En-route support

Is there a water source along the route in case it is needed?

8 Documentation

Verify the mandatory documents for transport.

9 Oxygen

Is oxygen available?

10 Team training

Are the staff properly trained for handling?

11 Euthanasia

Is there a euthanasia protocol for injured or moribund fish that cannot be transported?

Good practices in the transport of smolts or fingerlings

Smolt Transport Procedure

For Atlantic salmon smolts, planning should ensure transport densities in trucks do not exceed 100 kg/m^3. Remember that density depends on the route and the system's capacity to maintain temperature and minimum dissolved oxygen (DO) levels of >7 mg/L.

The entire transfer procedure from tanks to transport containers must be conducted in water with minimal air exposure.

Verify that all pumps, pipes, and hoses function correctly, and ensure a contingency plan is in place for equipment failures.

The oxygen diffusion system in transport tanks must be oil-free and capable of meeting oxygen requirements for at least 50% of the route, with an oxygen level monitoring system.

Transfer of smolts from trucks to wellboats should be done by gravity, always using smooth surfaces.

The wellboat must contain a system for additional CO_2 monitoring and be equipped with exhausters to maintain levels below 20 mg/L.

Wellboats generally recommend maximum densities of 50 kg/m^3.

During transit to marine culture sites, the wellboat must have a temperature control system to ensure that at the time of discharge, the water temperature in the tank does not differ by more than 2 °C from the sea temperature.

- Identify and separate sick, dead, or moribund fish.
- Do not crowd smolts for more than two hours.
- Maintain minimum levels of 7 mg/L DO in the holding tank and during transport
- Use densities less than 100 kg/m^3 in truck transport tanks
- Use densities less than 50 kg/m^3 in wellboats
- Ensure CO_2 levels below 20 mg/L in wellboats
- Ensure a temperature difference between the wellboat and the marine culture site of less than 2 °C

Good practices in the transport of smolts or fingerlings

Fingerling Transport Procedure

Use plastic bags resistant to the contact with the fish. In closed systems, the transport density depends on the route and the weight of the fingerlings, and can range from 50 to 500 g/L.

At high densities, the transport duration must not exceed 5 hours.

Use smooth materials during fish handling. For efficient biomass estimation, use standardized plastic slices for removing the fish from the water.

Perform the sampling by collecting the animals with the sieve and counting the number of individuals in one full scoop.

Repeat this procedure in three different locations within the batch to obtain a representative sample, then calculate the average number of fish per shipment.

Using this reference value, transfer the equivalent quantity of fish to a smooth, moist container placed on a calibrated scale to record the total weight. Dividing this weight by the number of fish sampled will provide the average individual weight with a controlled margin of error.

temperatura para que no momento da descarga, a temperatura da água no tanque não tenha uma diferença maior a 2 °C com a temperatura do mar.

Fill the bag with good quality water and the fish, using 1/3 of the bag's space, and fill the remaining 2/3 with pure oxygen.

For tilapia, the use of up to 6 g/L of non-iodized marine salt proves effective in reducing stress.

Do not use salt in the case of striped catfish transport.

The plastic bag must be sealed hermetically to prevent leaks. The plastic bags should be placed in cardboard or styrofoam boxes to maintain the temperature.

Transfer of smolts from trucks to wellboats should be done by gravity, always using smooth surfaces. The wellboat must contain a system for additional CO_2 monitoring and be equipped with exhausters to maintain levels below 20 mg/L.

Wellboats generally recommend maximum densities of 50 kg/m^3. During transit to marine culture sites, the wellboat must have a temperature control system to ensure that at the time of discharge, the water temperature in the tank does not differ by more than 2 °C from the sea temperature.

- Identify and separate sick, dead, or moribund fish.
- Do not crowd the fish for more than two hours.
- Maintain minimum levels of 5 mg/L of dissolved oxygen in the holding tank.
- Calculate the density in g/L according to the total transport time.
- Calcule la biomasa y el número de peces a ser asignados por bolsa plástica
- Calculate the biomass and number of fish to be allocated per plastic bag.
- Fill the plastic bag with good quality water to 1/3 of its volume.
- Place the bag in styrofoam boxes or plastic boxes.

Good practices in the transport of smolts or fingerlings

Reception of fingerlings

Upon reception of the animals, the fish must be unloaded into the new system without delay, with the bag still sealed.

Approximately 20 minutes after the bag has been in contact with the water of the new tank, open the bag and check the temperature inside it; it should not differ by more than 2 °C from the temperature of the reception tank water.

Ensure the reception water has a minimum concentration of DO >5 mg/L dissolved oxygen and ammonia <0.1 mg/L. Add water from the tank into the bag in small quantities every 10 minutes for 40 minutes.

Verify the temperatures and then carefully tilt the bag to allow the fish to enter the new tanks.

Good practices at transport for slaughter

Prior to transport, planning the harvest is essential to ensure appropriate handling and ensure the humane slaughter process.

Humane slaughter is all procedures from harvest to slaughter that comply with animal welfare principles.

During planning, the estimated total fasting time from feed withdrawal until the moment of slaughter must not exceed 24 hours for tropical species like tilapia and striped catfish, or 70 degree-days for Atlantic salmon.

Furthermore, based on the weight data from the last sampling, the density (kg/m^3) to be transported must be calculated. Remember that the transport vehicle must contain a basic support structure to maintain water quality parameters within the tolerance range for each species.

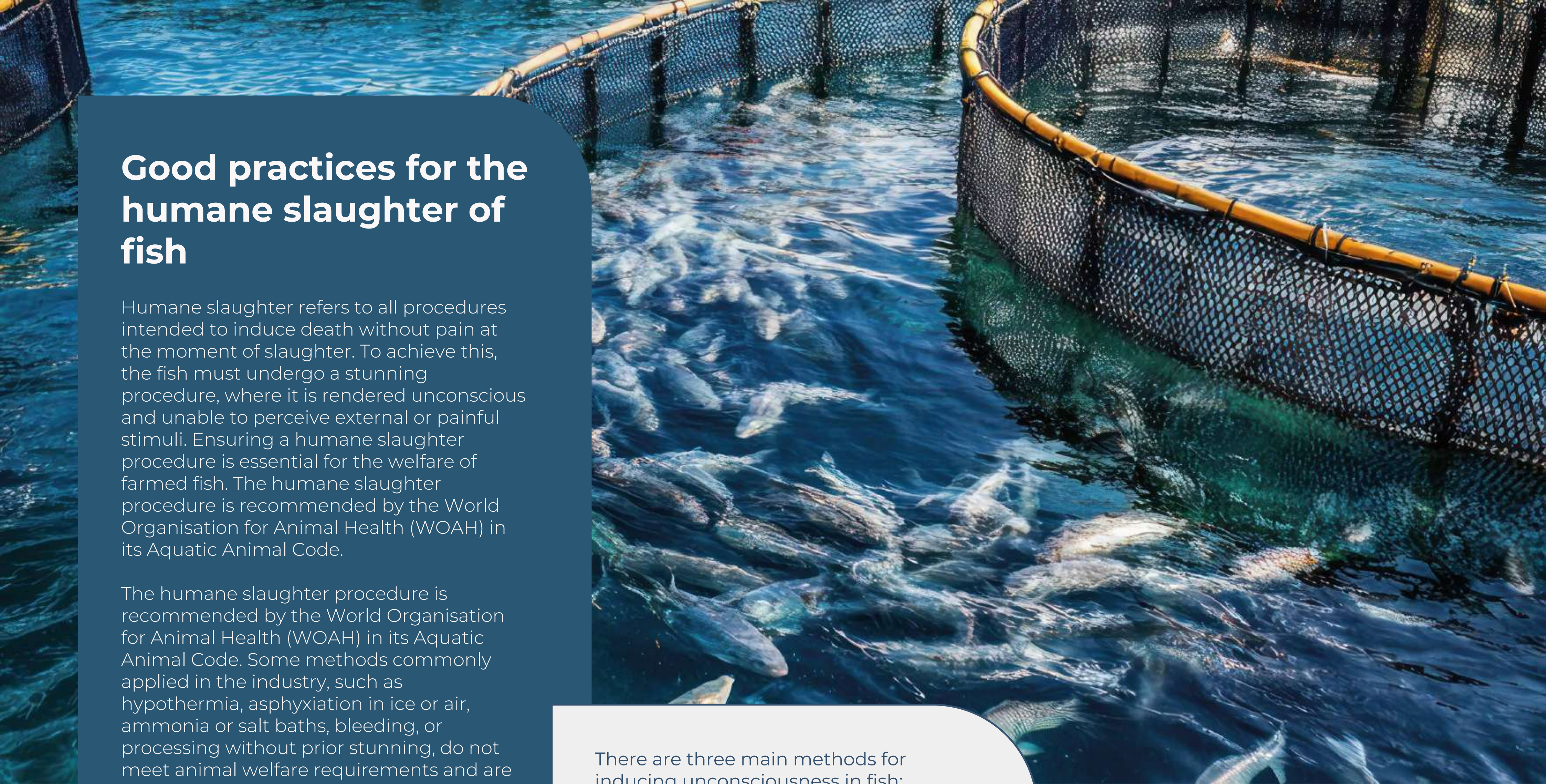
During harvesting, always use knotless nets and equipment with smooth surfaces to prevent injuries when coming into contact with the fish. Minimize as much as possible the time they remain out of the water (<30 seconds) by placing the fish into the transport tanks.

For tilapia, it is recommended to use 3-5 kg/m^3 of marine salt to help reduce stress during transport. Agricultural gypsum can also help reduce stress in tilapia at 1-2 kg/m^3. In water with total hardness greater than 80-100 mg of $CaCO_3$/L, there is no need to add gypsum to the transport water.

Upon arrival at the slaughterhouse, unloading must be carried out without delay. If there are reception tanks, they must be equipped with a system to keep water quality. Unloading should be done by gravity, ensuring no fish are left in the transport tanks and always minimizing the periods of air asphyxiation. Mortalities must be removed before the fish are conveyed to the slaughter room.

Good practices at transport for slaughter

- Prepare the mandatory documentation for transport
- Calculate the density in kg/m³
- For Atlantic salmon, use densities lower than 125 kg/m³
- For tilapia and striped catfish, use densities lower than 500 kg/m³
- Remember that density depends on the transport route duration and the support equipment available to maintain water quality within the tolerance range
- Include in the planning actions for unforeseen events and emergencies
- Verify that all utensils and equipment are functioning before the procedures
- In case of failures, ensure a support system is in place to maintain water quality for at least 50% of the planned route duration
- Use marine salt in the transport water for tilapia
- Unload the truck by gravity and without delay upon its arrival
- Maintain a record with transport information
- Remove mortalities
- Maintain a system to preserve water quality in the reception tanks
- Convey the fish to the slaughter room without air exposure



Good practices for the humane slaughter of fish

Humane slaughter refers to all procedures intended to induce death without pain at the moment of slaughter. To achieve this, the fish must undergo a stunning procedure, where it is rendered unconscious and unable to perceive external or painful stimuli. Ensuring a humane slaughter procedure is essential for the welfare of farmed fish. The humane slaughter procedure is recommended by the World Organisation for Animal Health (WOAH) in its Aquatic Animal Code.

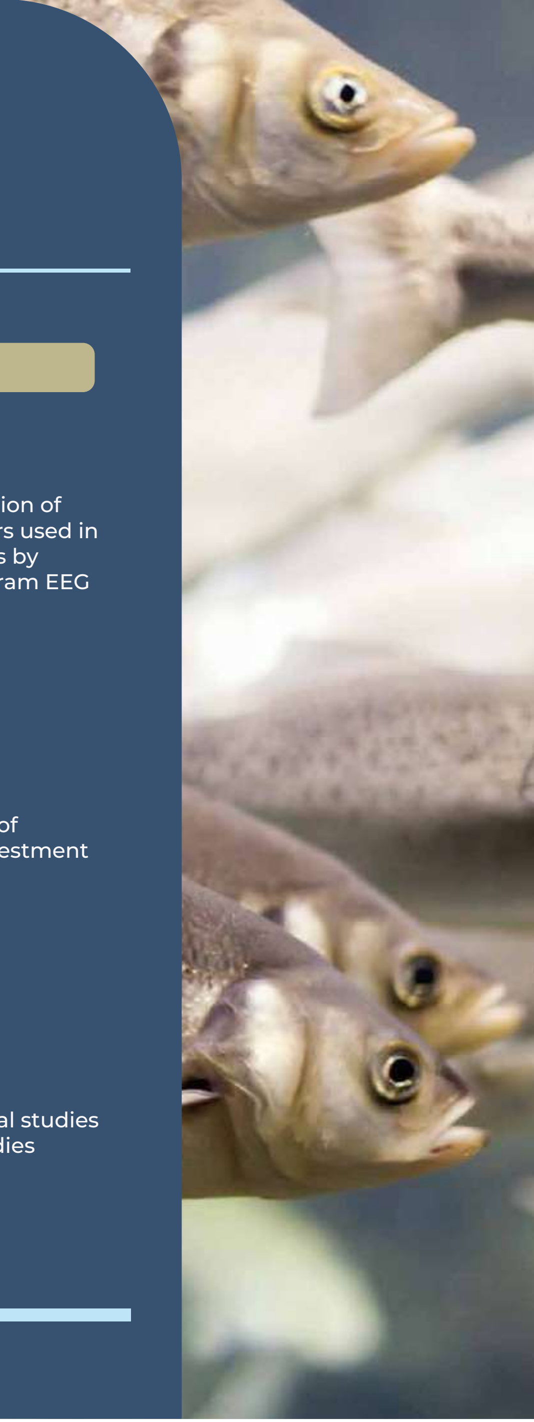
The humane slaughter procedure is recommended by the World Organisation for Animal Health (WOAH) in its Aquatic Animal Code. Some methods commonly applied in the industry, such as hypothermia, asphyxiation in ice or air, ammonia or salt baths, bleeding, or processing without prior stunning, do not meet animal welfare requirements and are therefore not recommended.

The use of technology is crucial to ensure efficient stunning at commercial slaughter volumes.

There are three main methods for inducing unconsciousness in fish: **electrical stunning, percussion stunning, or the use of anesthetics** (natural or chemical). Each method has its own advantages and disadvantages, as shown below (Table 12).

Table 12.
Advantages and disadvantages of stunning methods for fish, with the objective of humane slaughter.

	Advantages	Disadvantages	Remarks
Electrical stunning	High volume of processing In water stunning avoids dewatering	Risk of electroimobilization due to the use of electrical parameters without evidence in most species Temporary unconsciousness and risk for recovery during bleeding High cost of equipment's Risk for blood spots	Requires the validation of electrical parameters used in commercial settings by (electroencephalogram EEG studies)
Percussion stunning	If well applied induce permanent unconsciousness Without interference on the meat quality High volume of processing (8 mil fish/hour)	Requires a dewatering system High cost of equipment's	Requires high level of automation and investment
Deep anesthesia	High volume of processing Avoids a dewatering system Without interference on the meat quality Low cost of equipment	Low cost of equipment Lack of studies regarding food safety	Requires commercial studies and food safety studies



Electrical stunning

Electrical stunning can be performed in water, where electrodes create an electrical field within the water (Figure 1A), or out of water in a dry system, where electrodes make direct contact with the fish (Figure 1B). The latter system presents more welfare challenges since it requires a system to remove the fish from the water.

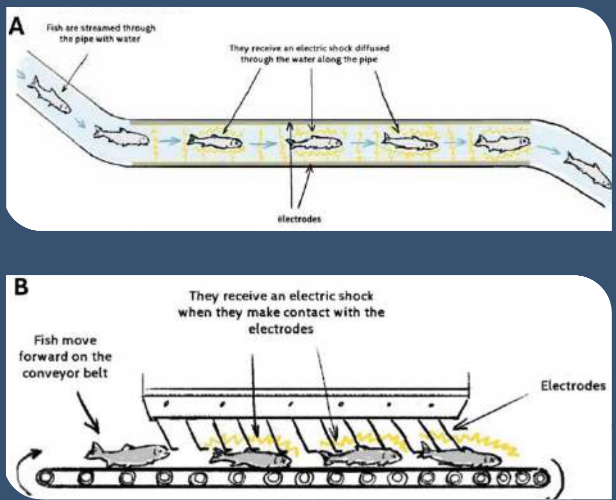


Figure 1. Possible systems for electrical stunning in Atantlic salmon, tilapia, and pangasius. Adapted from: WELFARM ©.

Concusión cerebral mecánica

Mechanical percussive stunning involves delivering a precise blow to the animal's head. This impact causes a neurological disturbance that rapidly induces unconsciousness. The head strike is administered using a non-penetrating captive bolt pistol. A restrainer ensures the fish are positioned correctly to receive the blow, targeting the brain.

Fish can enter the system manually (Figure 2A) or automatically via a water current that guides them into the restrainer (Figure 2B).

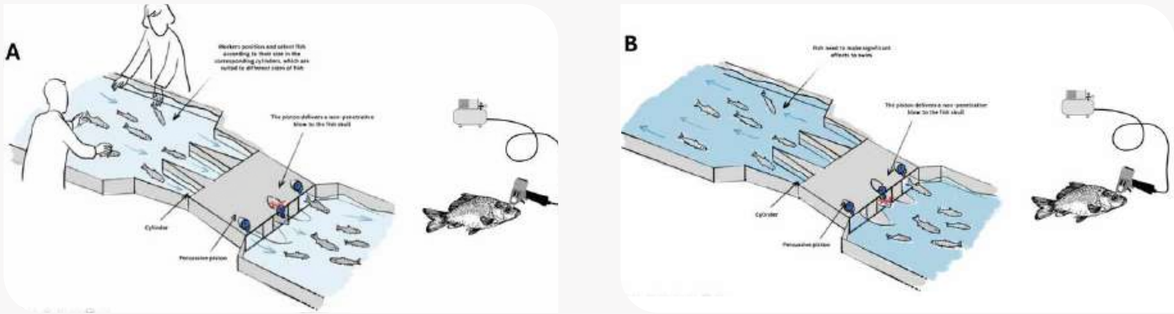


Figure 2. Mechanical percussive stunning system for Atantlic salmon, tilapia, and striped catfish. Adapted from: WELFARM © and LAMBOOIJ et al. (2007).

Method of stunning and re-stunning

At a part of activity at the slaughterhouse, it is essential to establish a protocol to assess the effectiveness of the stunning method and to re-stun any fish at risk of regaining consciousness. This assessment protocol must include at least three verification points: at the exit of the stunner, after the cutting of the aorta or gills for bleeding, and before processing. This ensures that 100% of the processed fish are dead (Figure 3).

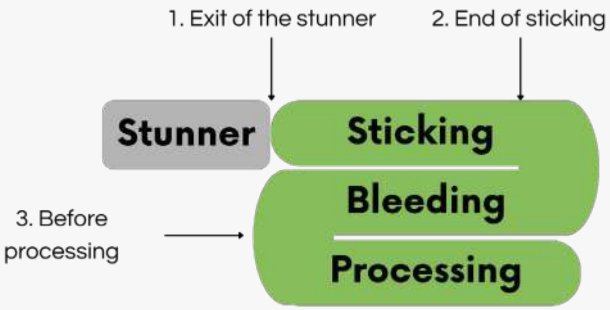


Figura 3. Diagram of the monitoring points for assessing stunning efficiency in fish slaughter.

The behavioral indicators to be observed during the monitoring of stunning efficiency are described in Table 13.

Any behavior suggesting consciousness or recovery of consciousness must be interpreted as a risk to animal welfare and must be immediately addressed with re-stunning.

Table 13.
Behavioral indicators to be observed in the monitoring of stunning efficiency in fish

Behavior	How to assess	Unconscious fish	Conscious or recovery conscious fish
Breathing (Air or water)	Observe the rhythmic opercular movement	No mouth or operculum movement	At least 2 movements of the operculum or mouth
Vestibulo-Ocular Reflex –VOR or eye roll (Air)	Observe eye movement when fish is rolled from side to side through the perpendicular	Eyes follow the movements of the head when rolled	One or both eyes tend to remain in the vertical position when rolled
Response to painful stimulus (Air)	Apply a pinprick to the fish's mouth	No response to a pinprick in the mouth	Responsive to a pinprick in the mouth, head shake or escape attempts
Response to handling (Water)	Apply pressure to the fish's tail	No attempts to move away	Partial response to handling
Equilibrium (Water)	Invert the fish, observe the righting response	Unable to right	Slow or quickly rights
Swimming behavior (Water)	Observe spontaneous swimming behavior	No swimming	Slow, abnormal or normal swimming

As a pilar of fish welfare at slaughter, it is recommended to record the number of fish that require re-stunning in order to continuously refine the stunning method.

The primary recommended method for applying re-stunning is mechanical percussion. The success of humane slaughter procedures depends significantly on training the staff to perform handling operations correctly, with minimal stress, and to identify conscious fish that require re-stunning.

A training program in humane slaughter ensures the process is refined and is not affected by staff turnover.

Final considerations

Animal welfare

Farm aquaculture success depends on the consideration of animal welfare

Balanced diets

The provision of balanced diets, including good feeding practices, ensures proper nutrition

Water quality

Water quality control is fundamental to ensuring comfort in the rearing environment

Preventive veterinary medicine

A preventive veterinary medicine plan allows for the management of stock health

In-water transport and slaughter

In-water transport and slaughter with prior stunning enable compliance with humane slaughter criteria

Monitoring the effectiveness of stunning

Monitoring the effectiveness of stunning is the key activity in the slaughterhouse

Enrichment environment

The enrichment environment strategies can help to improve capacity to cope with stress

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Written by: Daniel Santiago Rucinque
FWS Fish welfare consulting for aquaculture - Brazil

Review by: Minerva Foods Animal Welfare Team