DTU Aqua
National Institute of Aquatic Resources

Animal welfare in Denmark's fish farming sector: Regulatory and practical aspects

Manuel Gesto

DTU Aqua Report no. 474-2024

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Report summarizing the current knowledge on the status of animal welfare for fish and its assessment in the Danish aquaculture sector

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Title:	Animal welfare in Denmark's fish farming sector: Regulatory and practical aspects
Author:	Manuel Gesto
DTU Aqua Report no.:	474-2024
Year:	Scientific work finalized March 2024. Report published January 2025
Reference:	Gesto, M. (2024). Animal welfare in Denmark's fish farming sector: Regulatory and practical aspects. DTU Aqua. DTU Aqua Report no. 474-2024. https://doi.org/10.11581/c263c683-9311-4b2b-b3d1-ef7c7854ba14
Quality assurance:	Professor Britt Bang Jensen and Professor Per Bovbjerg Pedersen, DTU Aqua
Cover photo:	Trouts in aquaculture. Photo: Martin Dam Kristensen
Published by:	National Institute of Aquatic Resources, Technical University of Denmark, Henrik Dams Allé, 2800 Kgs. Lyngby, Denmark
Download:	www.aqua.dtu.dk/publikationer
ISSN:	1395-8216
ISBN:	978-87-7481-417-7

Preface

Fish welfare has become an important concern in aquaculture, mostly due to the recent increase in awareness of fish as potentially sentient animals among scientists and consumers. There is now a focus on fish welfare by policy makers and different initiatives are taking place as the recent creation of the EU Reference Centre for Animal Welfare for Aquatic Animals.

Within this context, DTU Aqua, with an established record of research efforts aimed at improving the welfare conditions of fish in aquaculture, has elaborated this report to establish the current status of this matter in Denmark and identify potential needs for future work at the national level. This report stems from an advisory task assigned by the Ministry of Food, Agriculture and Fisheries/Danish Veterinary and Food Administration.

Contents

1. Summary

The Danish aquaculture sector is mostly focused on the production of fish, which is in turn dominated by rainbow trout (*Oncorhynchus mykiss*), constituting 70% of the total aquaculture production and 88% of the total fish production in 2021[1].

Current regulatory framework in relation to the protection and promotion of animal welfare for fish in the aquaculture sector seems underdeveloped, in line to the current situation at EU level as recently reported (Pavlidis et al., 2023). Current applicable regulations often lack specific focus on the welfare of fish. Rules specifically established for fish tend to be generic statements without specific binding provisions, neither for fish in general nor for particular fish species. In this regard, rules in place for the farming conditions provided to the fish are not subject to specific regulations but are rather bound to the general protection provided to animals in the Danish Animal Welfare Act.

In lack of specific regulations for the conditions provided to the fish in Danish aquaculture, it is still in the best interest of the farmers to optimize the welfare of the fish, as good welfare conditions positively correlate with growth performance, increasing profitability. However, there seems to be very limited opportunities at national level for education or training in knowledge and methods to assess, protect and promote the welfare of farmed fish.

Current accessible information about the conditions provided to the fish in Danish fish farms, and about the welfare status of the fish is very limited, as there are no defined protocols for assessment and no surveillance in terms of welfare data collection and reporting. Contrary to other farmed animals, there are no publicly available reports about the welfare status of farmed fish.

For several of the farmed fish species in Denmark, current fundamental knowledge on their welfare needs is limited. However, there is good availability of information about fish welfare needs and welfare assessment tools for the two main species in Danish fish farming: rainbow trout and Atlantic salmon (*Salmo salar*), and, to a minor extent, for the third main species, the European eel (*Anguilla Anguilla*). Adopting rules, recommendations or guidelines to promote, assess and survey the welfare of these species in connection to operations on farm, during transport or at slaughter seems feasible based on current availability of knowledge and tools. For less studied species, generic guidelines and recommendations direct at minimizing potential welfare risks are also available.

All in all, several of the recommendations of a recent report on fish welfare at EU level (Pavlidis et al., 2023), are highly relevant to Danish conditions, including:

- Encourage societal awareness on fish welfare and support multi-disciplinary research on welfare of farmed fish.
- Support fundamental research on the welfare needs of farmed fish species in connection with the farming environment, for specific production systems, operational practices (crowding, transport, slaughter, etc.) and fish developmental stages.
- Support research and development of fit-for-purpose tools for welfare assessment such as species-specific operational welfare indicators, welfare scoring systems, and technology to monitor and assess fish behavior on-farm.

[1] https://stats.oecd.org/# on aquaculture production

- Develop educational tools and promote education and training of key personnel (veterinarians/health professionals, farmers) in relation to fish welfare needs and the use of fish welfare assessment tools.
- Promote research and development and industrial adoption of new technology to improve fish welfare, such as tools for continuous and/or automatized monitoring of fish welfare, or for humane slaughtering.
- Improve legislative framework to ensure the provision of good welfare conditions for farmed fish and its surveillance, considering species-specific needs.

2. Introduction

2.1 Fish welfare in aquaculture, a matter of increasing international concern

The consideration of fish as potentially sentient animals able to experience emotional states is relatively recent. Evidence from scientific research directed to investigate the ability of fish to process emotional information, including stress, pain, and fear, has led to a shift in people's ethical standards towards fish and to a general recognition of the need to protect their welfare (Bovenkerk & Meijboom, 2020). However, this concern is still not widespread. The current knowledge about fish welfare, in connection to human activities involving fish, is still limited, as are the tools and regulations to monitor, promote and protect the wellbeing of captive fish (Pavlidis et al., 2023). The welfare of farmed fish, and of fish used for other purposes (captured fish in fisheries, research fish, ornamental fish), has traditionally been neglected and overlooked. This has often been criticized by many voices from the general public and NGOs, but also by scientific bodies, and a series of initiatives and recommendations have been produced at EU level (Barreto et al., 2022; Browning, 2023; Manfrin et al., 2018; Pavlidis et al., 2023). One of the most recent initiatives is the creation of an EU Reference Centre for the welfare of aquatic animals[2], which started its activities in 2024 and will contribute with scientific and technical knowledge to support activities to meet welfare requirements of aquatic animals. Organizations active in the area of fish welfare also include the European Food Safety Authority (EFSA)[3], the World Organisation for Animal Health (WOAH)[4], the Standing Committee on Agricultural Research – Fisheries and Aquaculture Research –(SCARfish)[5], Aquaculture Advisory Council (AAC)[6], and others, including international as well as Danish NGOs such as Compassion in World Farming[7], Eurogroup for Animals[8], Aquatic Animal Alliance[9], Animal Ask[10], Dyrenes Beskyttelse[11], and others (Pavlidis et al., 2023). Main concerns about animal welfare relate to animal farming, and also to fisheries in the case of fish. The aquaculture sector is among the fastest-growing food sectors in the world (FAO, 2022). The sector is highly diverse in terms of the number of species farmed and the farming conditions and production systems, even for the same fish species. Together with the fast growth of the sector, this raises important concerns about the welfare of farmed fish. In this regard, it has been estimated that between 60 and 130 billion fish individuals were annually killed/harvested from aquaculture worldwide, and that only 30 % of those belonged to species for which there is any available scientific knowledge about their welfare needs (Franks et al., 2021).

Denmark has an important production of farmed fish, that amounted to 32100 tons in 2021[12], which was estimated to correspond to approx. 100 million of fish individuals[13]. Denmark is generally considered among the EU countries with a higher level of consideration of animal welfare[14]. However, the consideration given to fish does not seem to match that given to other farmed animals, in line with what happens in most other EU member states (Pavlidis, 2022; Pavlidis et al., 2023).

[2] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202400266
[3] https://www.efsa.europa.eu/en/topics/topic/fish-welfare
[4] https://www.woah.org
[5] https://scar-europe.org/fish-mission-and-aims
[6] https://aac-europe.org/en/
[7] https://www.ciwf.org.uk/
[8] https://www.eurogroupforanimals.org/
[9] https://aquaticanimalalliance.org/
[10] https://www.animalask.org/
[11] https://www.dyrenesbeskyttelse.dk/
[12] https://stats.oecd.org/# on aquaculture production
[13] https://www.animalask.org/post/farmed-fish-advocacy-in-denmark
[14] https://api.worldanimalprotection.org/country/denmark

2.2 Rationale and objective of this report

This report aims to describe the current state of knowledge about the welfare status of farmed fish in Denmark, including fish welfare in Danish fish farms and in farming-related operations such as live fish transport or slaughter, in terms of:

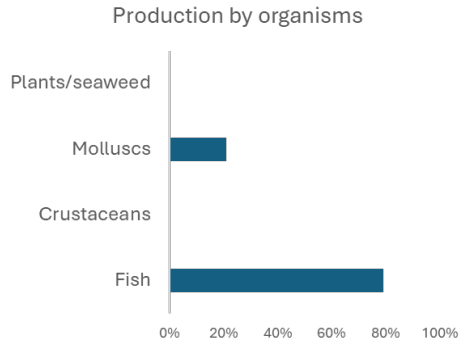
- Regulatory framework for fish health and welfare in aquaculture
- Fish welfare needs and factors affecting fish welfare in aquaculture
- Knowledge on welfare-friendly practices in aquaculture
- Assessment of fish welfare

This information is put into context in relation to current scientific knowledge and recommendations on fish welfare needs and available tools for assessment and monitoring of farmed fish at international level.

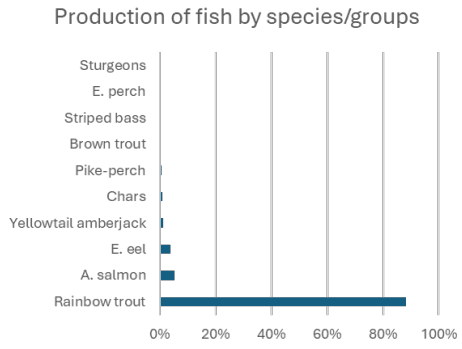
3. Fish farming in Denmark

3.1 Structure of the sector

In 2021, the total aquaculture production in Denmark amounted to 40,594 tons (excluding the transfers towards other aquaculture facilities)[15]. Fish accounted for 79% of those, the rest being mainly molluscs (21%, mussels) (Figure 1). Of the total 32100 tons of fish produced (not accounting dead/escaped), 88% was rainbow trout, 5 % Atlantic salmon and 4% European eel, with other species having a very minor production: kingfish/yellowtail amberjack (*Seriola lalandi*), char (*Salvelinus* spp), pike-perch (*Sander lucioperca*), brown trout (*Salmo trutta*), striped bass (*Morone saxatilis x Morone chrysops*), European perch (*Perca fluviatilis*) and sturgeon (Acipenseridae). From rainbow trout production (28,375 tons), 71% corresponded to production in freshwater and 29% were produced in sea farms (Figure 2). A fraction of the total rainbow trout production (2.3%, 654 tons) was certified as organic[16]. The production of three tons of organic brown trout is also reported in 2021, and the total organic fish produced accounted for 2.0% of the total fish production.



Organisms	2021 production (tons)
Fish	32100
Crustaceans (crayfish)	<0.5
Molluscs (blue mussel)	8485
Plants/seaweed (sea belt)	9



Species	2021 production (tons)
Rainbow trout	28375
A. salmon	1668
E. eel	1157
Yellowtail amberjack	386
Chars	265
Pike-perch	158
Brown trout	66
Striped bass	14
E. perch	8
Sturgeons	2

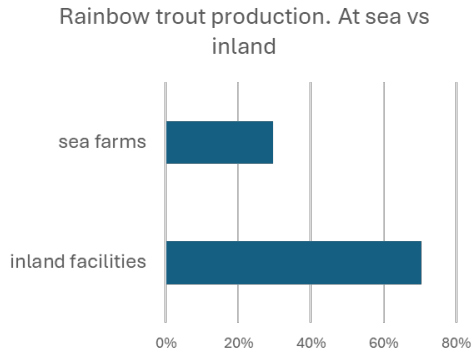
Figure 1. Denmark's 2021 production figures for aquaculture organisms. Data from https://stats.oecd.org/

The number of active fish farms in 2021 was reported to be 180 in total, with 43% being traditional farms (flow-through systems), 9% sea farms, and the rest being farms with some extent of water recirculation (low, medium or high)[17]. In total, tanks/basins were the most usual rearing units, followed by ponds, canals/raceways and cages. Production systems are diverse concerning water type, fish rearing technology and rearing unit design, even within the same species[18]. For rainbow trout, different

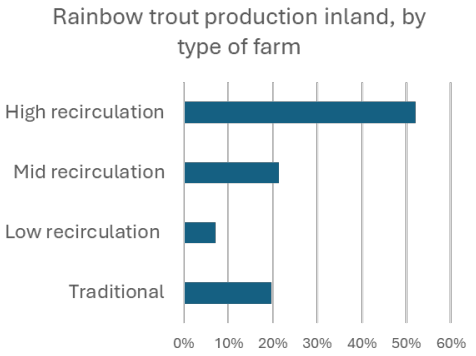
[15] https://stats.oecd.org/# on aquaculture production
[16] https://fiskeristatistik.fiskeristyrelsen.dk/stat/Akvakultur_tab/prod_oko_art_21_eng.html
[17] https://fiskeristatistik.fiskeristyrelsen.dk/stat/Akvakultur_tab/anlaeg_21_eng.html
[18] https://fiskeristatistik.fiskeristyrelsen.dk/stat/Akvakultur_tab/prod_reg_maengde_21_eng.html

developmental stages can rely on different production systems (for example, young trout can be produced inland and then be moved to sea cages for further growing). This methodological diversity in farming conditions is critical when considering the welfare of farmed fish, since different production systems impose different concerns and risks for the fish (Pavlidis, 2022; Pavlidis et al., 2023).

Geographically, inland farms using freshwater are concentrated in Jutland in the west of the country, while sea farms (including sea cages and facilities on land using sea water) are mostly located on the western coastline of Zealand and Lolland or the mid/ southeastern and western coasts of Jutland (Figure 3).



Facilities	2021 production (tons)
inland facilities	20012
sea farms	8363



Type of inland farm	2021 production (tons)
Traditional	4669
Low recirculation	1686
Mid recirculation	5081
High recirculation	12397

Figure 2. Denmark's 2021 production figures for rainbow trout by farm type.

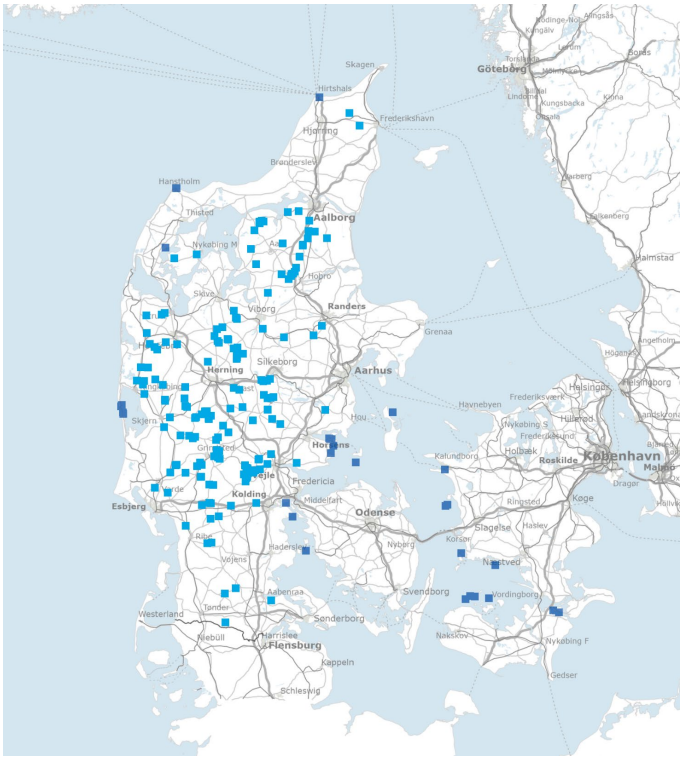


Figure 3. Location of freshwater (light blue) and seawater (dark blue) fish farms in Denmark by February 2024. From MiljøGIS[19], Miljøministeriet.

3.2 Regulatory framework for fish welfare in Danish fish farming

In Denmark, both animal welfare and animal health (including the prevention and control of animal diseases), among others, are under the responsibility of the Ministry of Food, Agriculture and Fisheries (as attributed by Order *BEK nr 1946 af 25/11/2020*). Within the Ministry, both subjects are under the responsibility of the Danish Veterinary and Food Administration (DVFA).

A. Specific regulation on fish welfare in Danish conventional fish farming

At present, there is no regulation concerning specifically the welfare of fish at conventional fish farms in Denmark. Fish welfare in aquaculture is nevertheless considered in connection with a more general regulation such as the Animal Welfare Act (*LBK nr 61 af 19/01/2024 Bekendtgørelse af lov om dyrevelfærd - dyrevelfærdsloven*)[20], which implements in Danish National legislation parts of the *Council Directive 98/58/EC of 20 July 1998 concerning the protection of animals kept for farming purposes*[21]. The Act provides general rules directed to "promote good animal welfare, including protecting animals, and promoting respect for animals as living and sentient beings". It makes no specific reference to fish, and it is applicable to any activity in connection with the use of animals, not only animal farming. The Act includes statements and rules for the general protection of animals and their welfare supervision, that refer to the treatment to animals during rearing/keeping, but also during other procedures relevant to animal farming such as transport or slaughter. As a generic regulation, there is no consideration of the particularities of fish as farmed animals, or about specific guidelines or requirements to monitor and ensure the welfare of fish. There is, for example, no explicit consideration in Danish law about the *Recommendations concerning farmed fish* from the *Standing Committee of the*

[19] https://miljoegis.mim.dk/spatialmap?profile=vandrammedirektiv3-2022
[20] https://www.retsinformation.dk/eli/lta/2024/61
[21] https://eur-lex.europa.eu/eli/dir/1998/58/oj

European Convention for the Protection of Animals kept for Farming Purposes, adopted by the Committee on 5 December 2005[22]. This includes recommendations focused on fish and directed to protect their welfare in fish farming in the EU but is not specific regarding particular species or production systems.

Other regulations, either specific for fish farming or indirectly affecting fish farming because of the use of live animals, fail to provide specific rules about fish welfare, but sometimes set rules that might indirectly affect animal health and welfare or their monitoring and reporting in fish farms. Those include:

- Act on the keeping of animals (*LBK nr 62 af 19/01/2024 Bekendtgørelse af lov om hold af dyr*)[23]. It regulates the keeping/holding of animals by humans, in connection to health of humans and animals and food safety. It attributes competences on fish farming to the Ministry of Food, Agriculture and Fisheries (registration of use, facilities, waste disposal). While it establishes general rules and responsibilities on animal and facilities registration, species approved, animal health and disease control, imports and exports of animals, etc., it does not consider specific rules for animal welfare.

- Order on freshwater farming (BEK nr 1567 af 07/12/2016 - Bekendtgørelse om miljøgodkendelse og samtidig sagsbehandling af ferskvandsdambrug - Dambrugsbekendtgørelsen)[24]. This applies only to freshwater fish farms. It establishes the rules to approve aquaculture facilities based on environmental variables related to water use and emissions, and/or feed quotas. It sets some minimum requirements in terms of farm design and operation, monitoring of environmental variables and their reporting for different types of freshwater farms. Fish welfare status is not considered, neither is the water quality provided to the animals in their units. In connection to welfare, the only relevant requirement refers to the obligation to report all entrance and exit of fish, including the amounts of dead fish (per period and species); abnormally high mortalities should be reported when they occur.

- The Order on the approval of listed companies (BEK nr 1083 af 09/08/2023 - Bekendtgørelse om godkendelse af listevirksomhed)[25] and the Environmental Protection Act (LBK nr 48 af 12/01/2024 -Bekendtgørelse af lov om miljøbeskyttelse - Miljøbeskyttelsesloven)[26] set together the regulations for the establishment and operation of freshwater and sea farms. The focus of these regulations is also on the environmental consequences of the farms and animal welfare is not considered. For sea farms, the approvals according to previous legislation apply until a new approval is needed. The previous regulation was the Order on saltwater farming (BEK nr 640 af 17/09/1990 Bekendtgørelse om saltvandsbaseret fiskeopdræt)[27], which was also focused on environmental impact of the farm. This regulation stated the requirement to monitor and report fish mortality in terms of weights and fish numbers, and to estimate and report escapees, also in terms of total weight and fish numbers.

- Order on the reporting of information on Danish aquaculture (*BEK nr 2288 af 03/12/2021 Bekendtgørelse om indberetning af oplysninger om dansk akvakultur*)[28]. This regulation describes the rules for data reporting from all Danish aquaculture facilities to the Danish Fisheries Agency (*Fiskeristyrelsen*), which in turn sends the info to Statistics Denmark (*Danmarks*

[22] Rec fish E (coe.int)
[23] https://www.retsinformation.dk/eli/lta/2024/62
[24] https://www.retsinformation.dk/eli/lta/2016/1567
[25] https://www.retsinformation.dk/eli/lta/2023/1083
[26] https://www.retsinformation.dk/eli/lta/2024/48
[27] https://www.retsinformation.dk/eli/lta/1990/640
[28] https://www.retsinformation.dk/eli/lta/2021/2288

Statistik). Statistics are to be categorized and reported according to farm type (traditional farms, low-, medium- or high-recirculation farms, sea farms, mussel/oyster farms, seaweed farms or "other" farms). From this regulation, aquaculture facilities need to report every year data about their facility type, number and type of fish rearing units, etc., status of activity (active or not), and data about the intake and output in terms of animal numbers and weight. The only marker in potential connection to welfare is the number of dead fish, as one of the categories of outputs – as stated in Appendix 3 of the Order, which are: -moved to other aquaculture facility, -exported live, -transfer to sea farms, - Internal transfer, -Consumption/slaughter, -to the wild; -put & take establishments; -Dead, discarded, escaped, - other. There is no discrimination between dead, discarded or escaped animals, and there is no reporting on the (potential) causes of death.

B. Specific regulation on fish welfare in Danish organic fish farming

While the production of organic fish in Denmark is very minor with respect to the total volume (2.0% in 2021)[29], the regulation about the welfare of organic fish is stricter than for conventional aquaculture. The regulatory framework for organic aquaculture in the EU is relatively young and has been changed or updated several times since the first rules appeared in 2010 (Busacca & Lembo, 2019). Organic aquaculture is currently regulated under the *Regulation (EU) 2018/848 of the European Parliament and the Council on organic production and labelling of organic products*[30], which is directly applicable to all EU member states since 1 January 2022. The Regulation contains both general statements and specific rules on the welfare of aquatic animals; those include fish, but also crustaceans, echinoderms, mollusks, and others. General statements include for example one of the general objectives of organic production (Art. 4): "contributing to high animal welfare standards and, in particular, to meeting the species-specific behavioral needs of animals". Also, among the general principles of organic production are "the observance of a high level of animal welfare respecting species-specific needs" (Art. 5), and "the application of animal husbandry practices which enhance the immune system and strengthen the natural defense against diseases, including regular exercise and access to open air areas and pastures".

Some specific rules and requirements for the organic farming of aquaculture animals are described in Part III of Annex II of the Regulation: "Production rules for algae and aquaculture animals", and some of the main rules affecting the farming of fish are summarized in Table 1 below. However, as there are knowledge gaps about the welfare needs of fish in connection with different production factors, especially for less-studied fish species, the Regulation did not initially define criteria for important variables, such as stocking densities and art. 15 of the Regulation empowered the European Commission to implement more rules in the future. Later, the *Commission Implementing Regulation (EU) 2020/464*[31] included additional detailed rules about the allowed stocking densities for different aquaculture animals in different production systems, including diverse fish species.

In Denmark, the DVFA guidelines in organic production[32], aimed to be informative to organic producers or marketers, go beyond Regulation 2018/848, and provide some specific ranges for some variables during the transport of organic fish, such as:

- Fish should not be exposed to large fluctuations of oxygen content of the water.
- Oxygen saturation should be within the range 65-120% at all times.

[29] https://fiskeristatistik.fiskeristyrelsen.dk/stat/Akvakultur_tab/prod_oko_art_21_eng.html
[30] EUR-Lex - 02018R0848-20230221 - EN - EUR-Lex (europa.eu)
[31] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02020R0464-20211125
[32] https://foedevarestyrelsen.dk/lovstof/vejledninger/oekologivejledningen

- Maximum duration of 6 h when water is not exchanged in the fish units. Maximum duration of 12 h in transport tanks, and 24 h maximum when combining transport and waiting time at slaughterhouse.
- Maximum stocking density of 150 kg m^{-3}.
- Salmonid fish should be fasted for 4-10 days before transport.

Table 1. Main production rules for organic fish farming with potential welfare-related direct effects, as set in Regulation (EU) 2018/848 of the European Parliament and the Council on organic production and labelling of organic products and as amended in Commission Implementing Regulation (EU) 2020/464. Updated from (Jokumsen & Svendsen, 2010).

Juvenile production	Conditions for larval rearing of marine fish species: - Maximum density < 20 egg or larvae/L. - Larval rearing tank: minimum volume 20 $m^{3.}$ - Larvae shall feed on natural plankton (can be supplemented by externally produced plankton.
Nutrition	Animal health and welfare should be a priority when designing feeding regimes.
Health and disease prevention	- Respect of welfare needs as the basis for prevention: "*disease prevention shall be based on keeping the animals in optimal conditions by appropriate siting, taking into account, inter alia, the species' requirements for good water quality, flow and exchange rate, the optimal design of the holdings, the application of good husbandry and management practices, including regular cleaning and disinfection of premises, high-quality feed, appropriate stocking density, and breed and strain selection*". - Health management plan: "*an animal health management plan shall detail biosecurity and disease prevention practices including a written agreement for health counselling, proportionate to the production unit, with qualified aquaculture animal health services who shall visit the farm at a frequency of not less than once per year* (…)".

Husbandry	- Husbandry environment should cover species-specific needs on:
	  - Available space/stocking density
	  - Water quality
	  - Temperature and light regimes.
	- Rules for stocking densities for different fishes were added in *Commission Implementing Regulation (EU) 2020/464*. For example, maximum densities of 25 kg/m^3 in fresh water, or 10 kg/m^3 in sea water (net pens) for rainbow trout.
	- For freshwater fish, "the bottom type shall be as close as possible to natural conditions".
	- "Operators shall keep records of monitoring and maintenance measures concerning animal welfare and water quality".

Production system design	"The design and construction of aquatic containment systems shall provide flow rates and physiochemical parameters that safeguard the animals' health and welfare, and that provide for their behavioural needs".

Farm personnel skills	"All persons involved in keeping aquaculture animals shall possess the necessary basic knowledge and skills as regards the health and the welfare needs of those animals".
Animal handling	"The handling of aquaculture animals shall be minimised and shall be undertaken with the greatest care. Proper equipment and protocols shall be used to avoid stress and physical damage associated with handling procedures. Broodstock shall be handled in such a manner as to minimise physical damage and stress and shall be handled under anaesthesia where appropriate. Grading operations shall be kept to a minimum and shall only be used where required to ensure fish welfare".
Artificial light	- Should not extend natural day length beyond a limit that compromises "ethological needs, geographical conditions and general health of the animals". - Should not exceed 14 hours per day (unless required for reproductive purposes). - Abrupt changes in light intensity should be avoided.
Aeration/oxygenation	- Mechanical aerators, preferably powered by renewable energy sources. - "Oxygen may only be used for uses linked to animal health and welfare requirements and for critical periods of production or transport (…)".
Transport	- Duration should be reduced to the minimum possible. - Live fish shall be transported in suitable tanks with clean water which meets their physiological needs in terms of temperature and dissolved oxygen. - Precautions shall be taken to reduce stress. During transport, the density shall not reach a level which is detrimental to the species.
Slaughter	- "Any suffering shall be kept to a minimum during the entire life of the animal, including at the time of slaughter - "Slaughter techniques shall render fish immediately unconscious and insensible to pain. Handling prior to slaughter shall be performed in a way that avoids injuries while keeping suffering and stress at a minimum. Differences in harvesting sizes, species, and production sites shall be taken into account when considering optimal slaughtering methods".

C. Regulation on fish health

Health is an inherent part of animal welfare and regulations on fish health will influence the management of welfare on fish farms. Regulations affecting fish health are in general directed to epidemiological control of animal diseases[33]. The main Regulation in place in connection to animal health is the so-called "Animal Health Law" (AHL) – *Regulation (EU) 2016/429 of the European Parliament and of the Council of 9 March 2016 on transmissible animal diseases and amending and repealing certain*

[33] https://www.eurl-fish-crustacean.eu/legislation

acts in the area of animal health[34]. AHL is directly implemented in Denmark, but there are supplementary national acts that ensure the applicability at national level. The Regulation sets rules for "the prevention and control of animal diseases which are transmissible to animals or to humans". While there is no particular focus on animal welfare status of the farmed fish, welfare is nevertheless considered indirectly in punctual parts of the Regulation and/or its amendments.

The AHL explicitly covers "aquatic animals, and animals which are not aquatic animals but which may transmit diseases affecting aquatic animals*"* (Art.3), and set specific rules for the control of different prioritized animal diseases (as "listed" or "emergent") in different groups of animal species. The Regulation covers various aspects of disease control such as setting general rules for the prioritization/categorization of animal diseases, surveillance protocols, animal health inspections, design of eradication programs, record keeping and reporting, and animal health documentation ("Health Certificates"), among others. The effect of a particular disease on animal welfare is considered as just one among many factors that determine whether the disease should be prioritized and included in the list of relevant diseases (Art. 7). Other points considering animal welfare include:

- Art. 10 states that animal operators are responsible for the health of their animals and for having good husbandry conditions, among others.
- Art. 11 states that operators need adequate knowledge about diseases and about the interaction between animal health, animal welfare and human health, among others.
- Art.12 states that veterinarians and aquatic animal health professionals, when active in the scope of this Regulation need, among other things, to help in "raising animal health awareness, and awareness of the interaction between animal health, animal welfare and human health".
- Art. 186 establishes record-keeping obligations of operators of aquaculture establishments, which include fish mortalities.
- Art. 208 describes the need for Health Certificates, for example, when transporting animals.

Beyond the AHL, other applicable regulations in connection to fish health/disease control include:

- Commission Delegated Regulation (EU) 2020/691 of 30 January 2020[35] supplements the Animal Health Law (above) about specific rules for aquaculture and transport of aquatic animals, mostly in connection with disease control.
- Commission Delegated Regulation (EU) 2020/990 of 28 April 2020[36] supplements the Animal Health Law to include rules about movements of aquatic animals, in relation to safety and disease control, and regulates the requirements for the animal health certifications to be issued by the competent authority, as well as veterinary check during animal movements.
- Commission Implementing Regulation (EU) 2018/1882 of 3 December 2018[37]. Enlists and categorizes diseases according to their relevance in EU, and states relevant affected species.
- Commission Implementing Regulation (EU) 2024/216 of 11 January 2024[38] updates the list of relevant diseases for aquatic organisms (fish, crustaceans, molluscs).

[34] https://eur-lex.europa.eu/eli/reg/2016/429/oj
[35] https://eur-lex.europa.eu/eli/reg_del/2020/691/oj
[36] https://eur-lex.europa.eu/eli/reg_del/2020/990/oj
[37] https://eur-lex.europa.eu/eli/reg_impl/2018/1882/oj
[38] https://eur-lex.europa.eu/eli/reg_impl/2024/216/oj

- Commission Delegated Regulation (EU) 2020/687 of 17 December 2019[39] states rules for prevention and control of certain listed diseases.
- Commission Delegated Regulation (EU) 2020/689 of 17 December 2019[40] details rules for surveillance protocols, eradication programs and diagnostic methods for different relevant enlisted or emergent diseases. This includes requirements for frequency of visits and samplings, and sampling protocols.

On a national level, some regulations are in place in order to support the AHL and its implementation in Denmark:

- The Order on lists of communicable diseases to the Act on the keeping of animals and on notification of diseases (*BEK nr 1341 af 27/11/2023 Bekendtgørelse om lister over smitsomme sygdomme til lov om hold af dyr og anmeldepligt af sygdommene*)[41] enlists relevant diseases at Danish national level and sets the rules for notification upon confirmation or suspicion to the DVFA.
- Order on monitoring and registration of Infectious Pancreatic Necrosis (IPN) and Bacterial Kidney Disease (BKD) (*BEK no 1492 of 12/12/2019 Bekendtgørelse om overvågning og registrering af Infektiøs pankreasnekrose (IPN) og Bakteriel nyresyge (BKD)*)[42], imposes Danish national rules on registration and surveillance of those two diseases affecting fish.
- The Order on health advise agreements for aquaculture companies (*BEK no 994 of 25/05/2021 Bekendtgørelse om sundhedsrådgivningsaftaler for akvakulturvirksomheder*) establishes the need for aquaculture companies in Denmark to establish an agreement with the competent authority, the DVFA, in connection to animal health advice. It sets rules on numbers of veterinary visits and general rules about the nature of the veterinary checks during those visits.

Current diseases affecting farmed fish that are part of the prioritized list of animal diseases in the regulations applicable in Denmark include: Epizootic haematopoietic necrosis (EHN), Viral haemorrhagic septicaemia (VHS), Infectious haematopoietic necrosis (IHN), Infection with highly polymorphic region - deleted infectious salmon anaemia virus (ISAV), Koi herpes virus disease (KHV), Infectious Pancreatic Necrosis (IPN) and Bacterial Kidney Disease (BKD).

D. Regulation on transport of fish

Disease control aspects of fish transport/movements are regulated as mentioned before in Commission Delegated Regulation (EU) 2020/69143. In terms of protection of the animals (i.e. animal welfare consideration), there is an EU regulation in place, the Council Regulation (EC) no 1/2005 of 22 December 2004 on the protection of animals during transport and related operations44, which is supplemented and incorporated in Danish law in the Order on the protection of animals during transport (BEK nr 26 af 13/01/2020 Bekendtgørelse om beskyttelse af dyr under transport)45. None of them makes any specific mention of fish, but general rules are set for the requirements associated with transport length and duration and with conditions during loading, transport and unloading. These rules do also apply to fish and are directed at ensuring that animals' safety is considered and that they are not harmed or suffer unnecessarily. There is a problem associated with the lack of specific regulations

[39] https://eur-lex.europa.eu/eli/reg_del/2020/687/oj
[40] https://eur-lex.europa.eu/eli/reg_del/2020/689/oj
[41] https://www.retsinformation.dk/eli/lta/2023/1341
[42] https://www.retsinformation.dk/eli/lta/2019/1492
[43] https://eur-lex.europa.eu/eli/reg_del/2020/691/oj
[44] https://eur-lex.europa.eu/eli/reg/2005/1/oj
[45] https://www.retsinformation.dk/eli/lta/2020/26

for aquatic animals, whose transport conditions are necessarily quite different to those needed for terrestrial animals. This has been the object of controversy in Denmark and elsewhere (Bachelard, 2022; EFSA, 2004; Henriksen, n.d.).

BEK nr 26 af 13/01/2020 does not add anything to EU Regulation in what respects to fish welfare. *Council Regulation 1/2005* covers fish welfare during transport without any specific mention to fish, just as "live vertebrate animals" (Art.1). Some general statements with potential implications for the welfare of the transported animals can be found in Art. 3 (General conditions for the transport of animals) such as:

- Animals should not be transported, loaded, or unloaded "in a way likely to cause injury or undue suffering to them".
- Personnel handling the animals should be competent or trained and should not use any methods "likely to cause unnecessary fear, injury or suffering".
- Animals should be provided with enough space and water, feed, and rest, "at suitable intervals and (…) appropriate in quality and quantity to their species and size".

Furthermore, Annex 1 deals with technical rules for transport protocols. Some examples of statements in connection to welfare, applicable to fish:

- Chapter 1 states that animals should be "fit for the intended journey" and imposes some limits on the transport of animals that are affected by injuries, diseases, or physiological weaknesses. Also prohibits the use of sedatives unless it is strictly necessary to ensure the welfare of the animals.
- Chapter 2 states rules in relation to means of transport, both generic or specific to certain transport means (by road, rail, air or sea). Generic rules in connection to welfare include statements directed to avoid injuries and suffering, protect animals from inclement weather, provide the animals with clean and adequate facilities during transport in terms of space, air quality, etc.
- Chapter 3 describes rules for transport practices in terms of loading/unloading procedures, handling, and potential need of separating some animals from others during the journey, most of these rules were made explicitly for terrestrial animals and often irrelevant for aquaculture fish.

E. Regulation on slaughter

For slaughtering animals, the main regulation in place is the *Council Regulation (EC) no 1099/2009 of 24 September 2009 on the protection of animals at the time of killing*[46]. This regulation set the rules in the EEA for the killing of animals "for the production of food, wool, skin, fur or other products as well as the killing of animals for the purpose of depopulation and for related operations". However, fish are explicitly mentioned as an exception in Art. 1 ("Subject matter and scope") that states they are only subject to the requirements laid down in Art. 3 point 1, which is a very general statement saying that "Animals shall be spared any avoidable pain, distress or suffering during their killing and related operations". Article 27 explicitly states the possibility to include further fish-specific rules for the killing of fishes, but there is no further applicable regulation on the matter at the time of writing this report.

[46] https://eur-lex.europa.eu/eli/reg/2009/1099/oj

At national level, there is the Order on killing, including slaughter, of animals (*BEK nr 817 af 15/06/2023 Bekendtgørelse om aflivning, herunder slagtning, af dyr*)[47], which describes some specific rules supplementary to Regulation 1099/2009 for the killing of animals in Denmark, namely in connection to training courses for personnel responsible for killing animals and for rules for killing in connection with religious rituals. Fish are not mentioned specifically but are affected by some general statements in chapter 2 of the Order that are very similar to some described in the Animal Welfare Act (*LBK nr 61 af 19/01/2024*). Those include "Animals must be spared any avoidable pain, mental stress or suffering during killing and related activities" and "Anyone who wants to euthanize an animal must ensure that the animal is euthanized as quickly and as painlessly as possible".

F. Regulation on animal welfare checks or inspections

In the EU, there is a common set of rules for the official control mechanisms to ensure that the legislation on animal welfare, among others, is respected. The rules are described on *Regulation (EU) 2017/625 of the European Parliament and of the Council of 15 March 2017 on official controls and other official activities performed to ensure the application of food and feed law, rules on animal health and welfare, plant health and plant protection products*[48]. This Regulation sets the common basis for different inspection programs, including those directed to ensure regulations on animal health and welfare during production, transport or at slaughter, among others. Those include regulations such as the *Council Directive 98/58/EC of 20 July 1998 concerning the protection of animals kept for farming purposes*[49], the Animal Health Law (*Regulation (EU) 2016/429*)[50], the *Council Regulation (EC) no 1099/2009 of 24 September 2009 on the protection of animals at the time of killing*[51], or the *Council Regulation (EC) no 1/2005 of 22 December 2004 on the protection of animals during transport and related operations*[52]. Among other things, it regulates the designation of competent authorities by the Member States and their general obligations in terms of official controls for the mentioned legislation, which include developing official control plans for "operators" (including fish farms). Art. 21 describes "Specific rules on official controls and for action to be taken by the competent authorities in relation to the welfare requirements for animals".

Furthermore, the Regulation also set rules for the creation and designation of EU Reference Laboratories and for EU Reference Centres on Animal Welfare. The EU Reference Centre of Aquatic Animal Welfare has been recently created and started its activities in 2024. According to the Regulation, the responsibilities of this new Reference Centre will include:

a) providing general scientific and technical expertise to relevant national support networks and bodies.

b) providing scientific and technical expertise for the development and application of animal welfare indicators.

c) developing or coordinating the development of methods for the assessment of the level of welfare of animals and of methods for the improvement of the welfare of animals.

d) carrying out scientific and technical studies on the welfare of animals used for commercial or scientific purposes.

e) conducting training courses for staff of the national scientific support networks or bodies, for staff of the competent authorities and for experts from third countries.

[47] https://www.retsinformation.dk/eli/lta/2023/817
[48] https://eur-lex.europa.eu/eli/reg/2017/625/oj
[49] https://eur-lex.europa.eu/eli/dir/1998/58/oj
[50] https://eur-lex.europa.eu/eli/reg/2016/429/oj
[51] https://eur-lex.europa.eu/eli/reg/2009/1099/oj
[52] https://eur-lex.europa.eu/eli/reg/2005/1/oj

f) disseminating research findings and technical innovations and collaborating with Union research bodies.

3.3 Societal awareness about fish welfare in Denmark

A consortium of several animal NGOs, led by World Animal Protection, have produced an Animal Protection Index (API)[53] that ranks fifty countries around the world according to their animal welfare policies and regulations. In general, Denmark is considered as a country that takes animal welfare seriously: the Danish Animal Welfare Act is considered as progressive and ambitious, and the country is scored B in a A-to-G scale from more to less animal welfare consideration[54] (no country is scored A). However, the general concern about fish within the current approaches and initiatives to animal welfare in the country seems to be rather limited. The main reason for this could be related to the fact that the evidence pointing to fish as potentially sentient animals is relatively recent. Some illustrative examples about the lack of societal penetration of fish as sentient animals include:

- As described in section 3.2 the regulatory framework for the protection and enforcement of fish welfare is limited when compared to other animals.
- The website of the DVFA, the competent authority on animal welfare, does not include "fish" as a separate category of animals within the "animal welfare" section of its website[55] (Figure 4).
- The governmental animal welfare label ("*Bedre dyrevelfærd*")[56], developed by DVFA, does not consider fish or fish products as potential holders of the label.
- The annual reports on animal welfare by DVFA[57] barely consider fish when reporting data on welfare official inspections (see also Section 5).
- Not much consideration or positioning about the welfare of fish is observed on the website, and findable reports therein, of the Danish Animal Ethics Council (*Det Dyreetiske Råd*)[58], as only one report about fish, a statement about angling from 2013 (Det Dyreetiske Råd, 2013), could be found when the website was accessed in February 2024.
- Information about fish welfare on the website of the Danish Aquaculture Organization- *Dansk Akvakultur* is scarce and limited to a short positioning statement (accepting that fish welfare is an important subject)[59].
- A recent illustrative example is the initiative by the Ministry of Food, Agriculture and Fisheries, which announced in January 2024 an animal welfare plan with twenty-three new initiatives to promote animal welfare, none of them directed at fish[60][61]

[53] https://api.worldanimalprotection.org/about
[54] https://api.worldanimalprotection.org/country/denmark
[55] https://foedevarestyrelsen.dk/dyr/dyrevelfaerd/landbrugsdyr-og-heste
[56] https://bedre-dyrevelfaerd.dk/servicemenu/english
[57] https://foedevarestyrelsen.dk/dyr/dyrevelfaerd
[58] https://detdyreetiskeraad.dk/
[59] https://danskakvakultur.dk/velfaerd-hos-opdraetsfisk/
[60] https://fvm.dk/fileadmin/user_upload/Dokumentation/SAMMEN_OM_DYRENE_.pdf
[61] https://fvm.dk/nyheder/nyhed/nyhed/foedevareminister-lancerer-udspil-23-initiativer-skal-indlede-nyt-kapitel-for-dansk-dyrevelfaerd

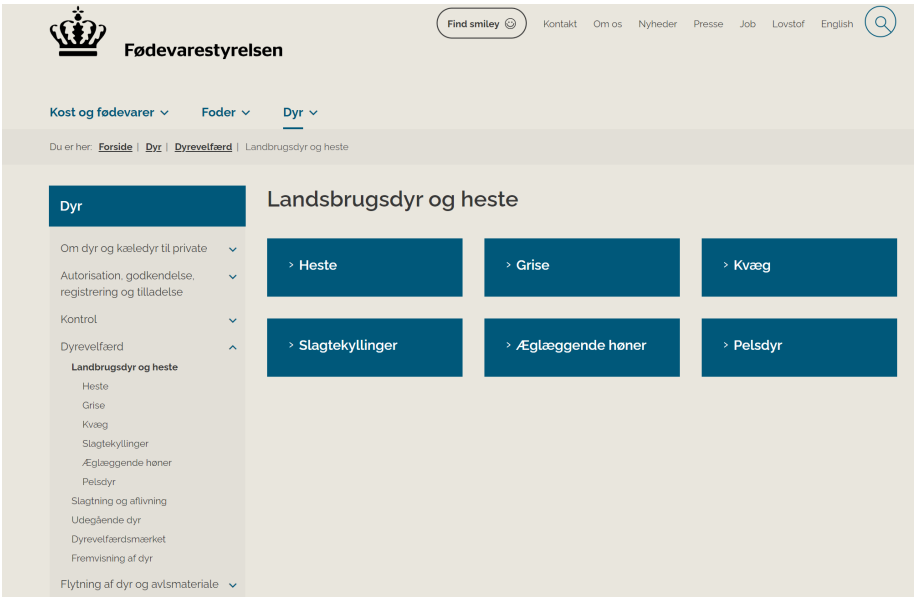


Figure 4. Groups of farmed animals mentioned in the animal welfare section of the DVFA website, where fish or other aquatic animals are omitted (screenshot from website as accessed on 28 February 2024).

4. State of the art about fish welfare and its monitoring in fish farming

4.1 Animal welfare and fish

There are many definitions and some controversy around the concept of fish welfare (Kristiansen & Bracke, 2020), but in simple terms, welfare could be defined as “the physical and mental state of an animal in relation to the conditions in which it lives and dies” (WOAH, 2023). Ethical approaches on animal welfare have been traditionally based on accepting the need of keeping animals free of negative experiences on five “domains”: nutrition, physical environment, health, behavioral interactions and mental state (Mellor, 2016). More recent trends in the five domains model recommend shifting from being free from negative experiences towards the need to provide positive experiences and promote a good “quality of life”, also when considering the human-animal interactions (Mellor et al., 2020).

The consideration about the welfare of fish lags behind that of terrestrial farmed animals (Pavlidis et al., 2023). This is believed to be due to several factors, such as the relatively recent awareness about fish as sentient animals, or the difficulties associated to observation and perception of the emotional states from fish, as they are difficult to access visually, particularly in the fish farming context, and are less expressive than other vertebrates. Furthermore, huge numbers of wild fish are captured in fisheries and the welfare constraints associated with their capture have started to be recognized only recently. Recent research and new technology have advanced the knowledge about fish welfare needs and provided tools to assess fish welfare. However, assessing and monitoring fish welfare is still complicated, and this is hampering the development of tools to promote animal welfare and legal mechanisms to protect it in fish farming and other activities involving fish. Above all, there is a clear gap of knowledge and lack of available data about assessments of fish welfare in the farming and the fisheries contexts. That kind of data would be critical in order to know what to expect and how to regulate the welfare protection of fish. The following lines provide a summary of the current knowledge about the welfare of farmed fish and the available tools for its assessment and monitoring.

4.2 Fish welfare needs and factors influencing the welfare of farmed fish

Welfare of fish in the farming environment is essentially determined by the extent to which farming factors and conditions are able to accommodate the welfare needs of the fish and is also subject to the occurrence of unexpected events such as disease outbreaks or other stressors. Farming conditions experienced by the fish will differ substantially depending on production system, farm design, operational conditions, farm location, etc. Fish welfare needs depend on fish species, developmental stage and production phase. Current knowledge in relation to the effects of specific farming factors/conditions on the welfare of particular fish species and stages is very uneven and is considered very limited with some exceptions (Franks et al., 2021; Pavlidis et al., 2023).

It is generally assumed that practices favoring fish welfare will also favor the economic sustainability of a fish farm, since fish under poor welfare conditions underperform in terms of growth and resistance to diseases. Because of this, it is in the best interest of fish farmers to provide conditions to the fish that promote their welfare on farm, during transport and at slaughter (Segner et al., 2019).

Farming factors influencing fish welfare

Both intrinsic and extrinsic factors determine the welfare of farmed fish. **Intrinsic factors** are mostly related to the genotype of the farmed animals and to their level of domestication and adaptation to the

farming protocols (Saraiva et al., 2019b). **Extrinsic factors** are all those external to the fish, in relation to the living conditions the fish experience on the farms (EFSA, 2008a, 2008d, 2008e, 2008c, 2008b; Huntingford et al., 2006; Santurtun et al., 2018; Stien et al., 2020), including:

- captivity (itself a welfare issue)
- the design and level of enrichment of the rearing units
- water quality
- environmental conditions (light, temperature, noise, weather effects, etc.)
- diet and feeding regime
- social environment (numbers, size, and type of cohabitants in the rearing unit)
- episodic exposure to stressors (predators, intraspecific aggression, handling, netting, crowding, transfers, vaccinations, use of disinfectants, etc.)
- punctual or sustained disease or parasitic outbreaks.

How relevant each factor is in determining or influencing the welfare of the farmed fish depends on fish species, developmental stage, production systems, production stage, etc. (Pavlidis et al., 2023; van de Vis et al., 2020). Some factors might become relevant at specific moments (e.g. during smoltification in salmonids) or developmental stages, or during particular operations during the life of farmed fish such as during transport or at the time of slaughter (Saraiva et al., 2024; van de Vis et al., 2020).

For some specific welfare-relevant factors in fish farms, their effects on welfare are relatively well understood because there is a good base of scientific research. Well known factors often include those associated with critical welfare needs of the fish and that directly affect their survival and growth such as water temperature, oxygen availability, salinity, dietary needs, etc. But many factors can affect fish welfare in more subtle ways and are often not well understood. For example, issues impacting welfare can differ in the timing of occurrence. Some can be acute and easy to detect (such as predator attacks, disease outbreaks or stress episodes because of transport or transfers), while others might occur chronically affecting the fish subtlety for long times and can easily occur unnoticed (such a suboptimal design of the rearing units, suboptimal social context, etc.) (Jones et al., 2021). Additionally, some factors can also interact with each other and affect welfare in complex ways (Adams et al., 2007; Ashley, 2007) which are not well understood, most often. One complex and often discussed factor is fish stocking density (the total fish biomass per unit of water volume in the fish rearing unit), which has been object of regulations in connection to fish welfare (such as in previous EU rules for organic aquaculture). The effects of stocking density can be affected in a complex manner by different factors (species, life stage, domestication level, rearing unit size and relative dimensions, water quality, water circulation, etc.) (Ellis et al., 2002; Noble et al., 2020), making it very difficult to regulate on minimum or maximum limits. A preferred approach would be focusing on the actual effects on fish behavior and condition (Noble et al., 2020), as in the current EU regulations on organic aquaculture (see section 3.2B, Table 1). Some documents still provide recommendations on specific limits (most usually for maximum stocking densities), such as the RSPCA standards for salmon and trout (RSPCA, 2020, 2021). There are also other production variables in fish farming for which their potential effects on fish welfare are poorly understood, particularly in connection with the levels of environmental enrichment in the fish rearing units: rearing unit dimensions, materials, color, water currents and their timing, lightning protocols, stability/predictability of rearing conditions, etc. (Arechavala-Lopez et al., 2022; Jones et al., 2021).

Fish welfare needs

Fish is a highly diverse group of animals. Different farmed fish species have specific needs in relation to all the factors relevant to welfare mentioned above. Conditions provided to the fish on farm, but also during transport and at the time of slaughter should be able to accommodate both the

physiological and behavioral needs of the fish. However, the knowledge about the welfare needs of many farmed fish species, and about how their welfare is affected by the intrinsic and extrinsic production factors is uneven. While some species have been the object of extensive research and their welfare needs are relatively well known (e.g. Atlantic salmon), there are many farmed fish species worldwide for which the knowledge on their biological and welfare-related needs is lacking or very limited; and this is recognized as a critical gap of knowledge and an important issue for the development of the aquaculture industry (Franks et al., 2021).

Furthermore, welfare needs can be different for a given species depending on the developmental stage or production phases (Manfrin et al., 2018; Pavlidis et al., 2023; van de Vis et al., 2020). Welfare needs can also differ depending on the type and purpose of the fish being farmed: welfare needs of fish intended for human consumption can differ from those of fish intended for restocking wild populations, as fish for restocking will need to keep wild-like behavioral types for better survival upon release (Braithwaite & Salvanes, 2010).

Conditions imposed on the fish are very different for different production systems (flow-through systems, RAS, cages at sea, etc.) (van de Vis et al., 2020), but also depending on the type of rearing units (ponds, raceways, tanks, cages, etc.) and their design, which can be quite different even for the same type of unit in terms of dimensions/space use, materials, colors, textures, etc. The knowledge about how the production system and rearing unit design affect the welfare of fish is far from complete for many farmed fish species. Beyond conditions for fish during their life on the farm, consideration of fish welfare is important also in punctual events such as during transport, treatment or sorting processes, and at the time of slaughter, when specific welfare need might arise. During these events, the needs of the animals should also be considered to minimize the extent of suffering in terms of distress, anxiety or pain.

Salmonid fish such as Atlantic salmon or rainbow trout are among the species for which there is good availability of scientific studies about their biology and welfare needs. There are also several published documents compiling information about those welfare needs in connection with recommendations and good practices for fish farming purposes, including the provision of farming conditions adequate to the welfare needs of the fish, but also tools to assess or monitor fish welfare at fish farms. There are for example manuals for both A. salmon and rainbow trout published by Nofima (Norway) as reports from the FISHWELL project[62], that review the welfare needs of the species and the available tools to assess it at different production systems (RAS, flow-through, cages) and at different operations (on-farm, during transport, at slaughter, etc.) (Noble et al., 2018, 2020). The UK animal charity RSPCA (Royal Society for the Prevention of Cruelty to Animals) has also published welfare standards for the farming of both species[63][64], setting conditions on a number of welfare-relevant factors on farm and during transport and slaughter (RSPCA, 2020, 2021). The RSPCA document for A. salmon also provides guidelines for the farming of cleaner fish (wrasses and lumpfish) used to help in controlling sea lice infestations in salmon farms.

The EFSA published in 2008 “scientific opinion” reports on specific fish welfare needs for Atlantic salmon and trout (rainbow trout and brown trout), but also for European eel, European seabass and gilthead seabream, and common carp. EFSA reports covered welfare risks and recommendations for different life stages/production phases in different production systems (EFSA, 2008a, 2008d, 2008e, 2008c, 2008b). EFSA also published in 2009 another series of reports specifically covering welfare

[62] https://nofima.com/press-release/download-the-fishwell-handbooks/
[63] https://science.rspca.org.uk/sciencegroup/farmanimals/standards/trout
[64] https://science.rspca.org.uk/sciencegroup/farmanimals/standards/salmon

aspects of stunning and killing methods for fish. These reports provide recommendations for eight different species: bluefin tuna, common carp, European eel, Atlantic salmon, rainbow trout, European turbot, European seabass and gilthead seabream (EFSA, 2009e, 2009f, 2009b, 2009c, 2009d, 2009g, 2009a).

For other species, knowledge is most often limited and scattered (Saraiva et al., 2019a). The Fair-Fish database is a public database under development compiling information about biological and welfare needs of fish species under different contexts (wild, captivity)[65]. It currently contains accessible information (to an extent that differs a lot among species) for 87 aquatic animal species, and for 11 of them there are recommendations for farming practices or conditions available.

4.3 Assessment and monitoring of fish welfare – Available tools and protocols

Welfare assessment in fish is usually done by using a combination of different types of welfare indicators to determine the welfare status of the fish as accurately as possible (Gesto, 2021). A variety of welfare indicators are commonly proposed for their use in fish farming (see examples in Figure 5), but the assessment scheme to follow will depend on the fish species, the resources available, and the purpose of the assessment. It is generally considered that the welfare assessment scheme should include both input-based and outcome-based welfare indicators (Stien et al., 2020). Input-based indicators are informative about the conditions provided to the fish in terms of physical and social environment, and production protocols. Optimally, the conditions provided should accommodate the welfare needs of the particular species on the farm. However, the welfare of the fish can be affected by uncontrolled factors, or by unexpected or unknown issues and it is therefore needed to include outcome-based indicators. Outcome-based indicators are animal-based indicators, either individual- or group-based, that are directly informative about the status of the fish (Figure 6) (Kristiansen et al., 2020; Stien et al., 2020).

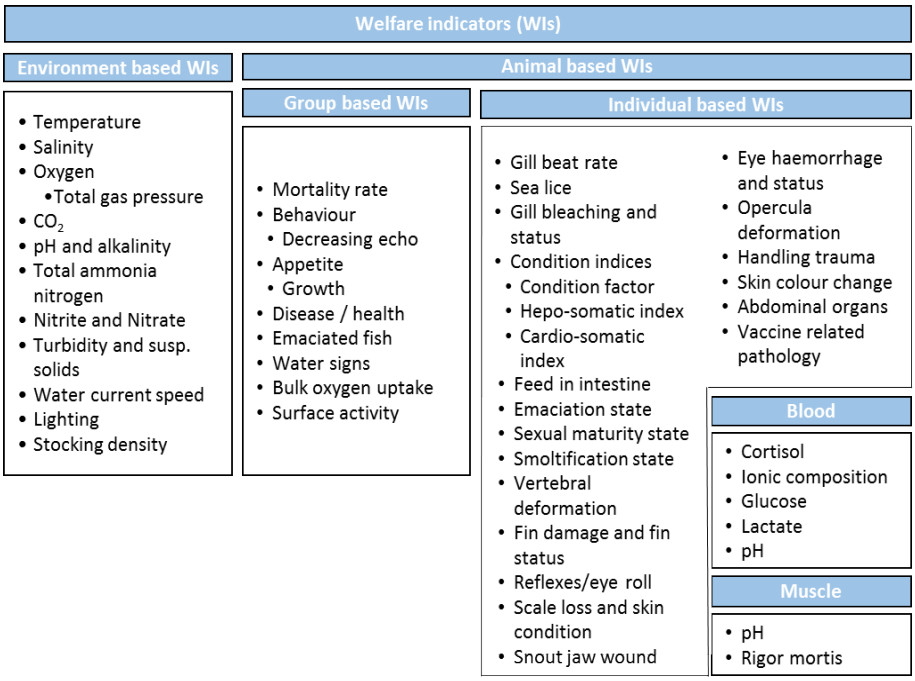


Figure 5. Examples of Welfare Indicators for fish including environmental indicators (input-based) and animal-based indicators ("Outcome-based"). Figure extracted from Fig. 5.5-1 in (Noble et al., 2018).

[65] https://fair-fish-database.net/

On a different classification, welfare indicators are often categorized as Operational Welfare Indicators (OWIs), or as Laboratory-Based Welfare Indicators (LABWIs) (Martins et al., 2012; Noble et al., 2018, 2020). OWIs are more practical, relatively unexpensive and can be measured directly on the farm. LABWIs are generally very accurate and informative about the health and welfare status of the fish but require laborious and more complex laboratory analysis, are usually more expensive, and might not be applicable as routine measurements in a farming scenario.

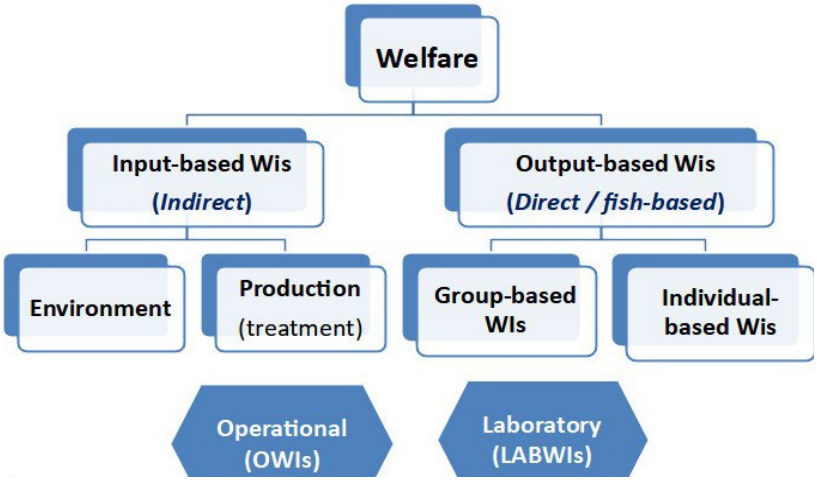


Figure 6. Types of welfare indicators. Figure extracted from Fig. 1 in (Pavlidis, 2022) which was in turn modified from (Stien et al., 2020).

In fish farming, a welfare scheme should be fit for the purpose and using OWIs that are as informative as possible while being practical, would be initially preferred (Stien et al., 2020). However, the use of OWIs might not always be enough. Noble et al. (2018) suggested the use of a hierarchical approach to welfare assessment to rationalize the use of resources according to the needs of particular situations (Figure 7). The recommended system could be adapted to different species and included three levels of complexity when assessing welfare: The assessment would be restricted to level 1 (using basic and easy to measure input- and outcome indicators) when no alterations are found, and will only move to higher levels as needed, resorting to more complex indicators (more resource-demanding OWIs and LABWIs), when there is an ongoing welfare issue that requires a more accurate assessment.

Many welfare indicators are well established and have been used multiple times for different species, most often in the scientific research context, as detailed welfare assessment in aquaculture fish is still not widespread. But the field of fish welfare indicators is still evolving and initiatives for innovative indicators are ongoing (Barreto 2022).

Regarding available protocols, detailed guides with proposals for adequate welfare indicators for Atlantic salmon and rainbow trout in different production systems have been published in the FISHWELL reports (Noble et al., 2018, 2020). But suggestions for alternative schemes have also been published in scientific journals for those very same species, such as the fish welfare evaluation index (fWEI) for rainbow trout in flow-through systems (Weirup et al., 2022) or the salmon welfare index model 2.0 (SWIM 2.0) for Atlantic salmon in sea cages (Pettersen et al., 2014). Currently, there is no “golden standard” regarding welfare assessment for these or other species; for non-salmonid species, published protocols for welfare assessment are rarely available. For cleaner fish, proposals for welfare indicators or welfare assessment manuals have been recently published. Those include

manuals[66] for welfare assessment in lumpfish (*Cyclopterus lumpus*) in hatcheries (Boissonnot et al., 2022a) or in sea cages (Boissonnot et al., 2022b), and proposals for welfare indicators in lumpfish (Noble et al., 2019b) and ballan wrasse *Labrus bergylta* (Noble et al., 2019a) from the RENSVEL project[67]. A welfare index based on scoring different welfare variables was also developed and validated for lumpfish (Gutierrez Rabadan et al., 2021). A proposal to assess the welfare of farmed Nile tilapia (*Oreochromis niloticus*) in semi-intensive production systems is also available (Pedrazzani et al., 2020). Furthermore, a relatively simple generalist model called "MyFishCheck", adaptable to different species, has been developed along with a user-friendly app to be used as a welfare assessment tool on farms (Tschirren et al., 2021).

Knowledge gaps in connection to welfare assessment relate to the lack of knowledge of welfare needs of many species, as commented above, but also to the lack of available welfare assessment protocols for most species. And for almost all species, including salmonids, there is a critical gap of knowledge in relation to the welfare status of the fish in fish farms. This is because, even for species for which welfare assessment protocols are available, the use of those is not widespread and data on the results of their application is rarely reported. Also, legal requirements for having surveillance programs in place for fish welfare are scarce. As a result, current data availability about welfare indicators and welfare scores of fish welfare in aquaculture, beyond annual reports on fish mortalities that are reported in some countries, is very low.

While potential welfare surveillance programs could be based on periodical assessment of welfare indicators, there are ongoing efforts to develop new technological tools that could allow for the continuous monitoring of fish welfare. These are still under development and are mostly based on monitoring the status and behavior of the farmed fish using video-monitoring or telemetry tools such as accelerometer tags implanted inside a few sentinel fish, that can send data to receivers (Alfonso et al., 2022; Barreto et al., 2022; Morgenroth et al., 2024). Data handling using machine learning and AI is developed to handle large amounts of data even in real time, so alterations in fish behavior could be used as a proxy for alterations of the welfare status of the fish (Eguiraun & Martinez, 2023; Mandal & Ghosh, 2023; Ranjan et al., 2023; Zhao et al., 2021). Besides monitoring behavior, these tools could also be used to detect or monitor some external anatomical indicators such as external damage to tissues, occurrence of ectoparasites like sea lice, or emaciation (MacAulay et al., 2022). Some implanted sensors in sentinel fish can also provide physiological information linked to stress and welfare such as heartbeat rates and other (Brijs et al., 2019; Hvas et al., 2020; Martos-Sitcha et al., 2019; Morgenroth et al., 2024). The use of these technologies is still not widespread in the industry but is gaining pace fast, in particular where the industry has economic power to justify the elevated costs associated to their development or implementation.

[66] https://aqua-kompetanse.no/lumpfish/
[67] https://nofima.com/projects/rensvel/

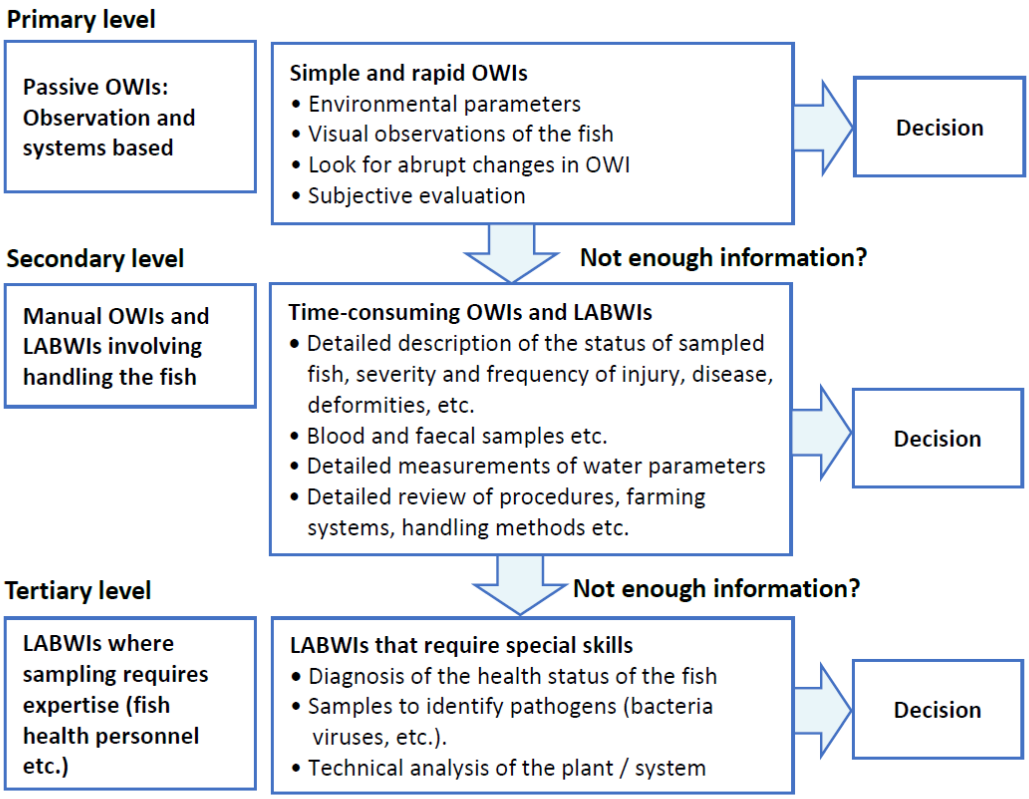


Figure 7. Scheme of a hierarchical approach to welfare assessment in a fish farm. Extracted from Fig. 5.1-1. in (Noble et al., 2018).

5. Danish trout farming conditions and fish welfare

5.1 Conditions on fish farms

As there are very limited legal requirements directly affecting the welfare of the farmed fish or its monitoring, beyond recording and reporting mortalities, there is very limited information about to which extent the farming environment is adequate to the welfare needs of the fish (input-based indicators), or about the actual welfare status of the fish in the farms (outcome-based indicators). Available data on the actual welfare status of the fish in Danish fish farms is anecdotical (Eidsmo et al., 2023; Henriksen et al., 2022; Toomey et al., 2024). Those constitute critical gaps of knowledge, as the lack of data impedes benchmarking Danish fish farming conditions to expected standards in connection to animal welfare according to the Animal Welfare Act and other regulations. The DVFA publishes every year a report on animal welfare in Denmark summarizing the results of official inspections on different farmed animals[68]. These reports show no information about the welfare of fish on farms.

The regulations for organic aquaculture consider different aspects of fish welfare, but rules are mostly very generic statements and provide no specific recommendations on input- or outcome-based welfare indicators, apart from some specific guidelines for the transport of organic fish[69] as mentioned in section 3.2. Like in conventional aquaculture, there is no data or reports available about the welfare status of organic farmed fish. It is perhaps important to mention that since organic principles pursue different aspects of sustainability, some of the measures taken can generate conflicts between different aspects. For this reason, it might be that some of the organic production rules have punctual negative effects on animal welfare. This could include for example the rules directed to limit the use of medication and disinfectants, which can have negative consequences for the welfare of farmed fish in connection to the occurrence of diseases.

In relation to fish health and disease control protocols, fish farms are visited regularly by a veterinarian (according to *BEK nr 994 af 25/05/2021 Bekendtgørelse om sundhedsrådgivningsaftaler for akvakulturvirksomheder,)* and general health of the animals is expected to be observed in connection to the periodic visits (six per year), but it is unclear to which extent these checks account for welfare issues different from diseases. Furthermore, there seems to be little official control over the realization and results of those visits, as there is no data or official statistics available about them.

There is little publicly available information about the educational/training possibilities in Denmark for key personnel involved in the care or inspection on fish welfare (caretakers, inspectors, private or governmental fish veterinarians). No information in this regard could be found in the animal welfare section of DVFA website as accessed in February 2024. During the elaboration of this report, educational activities with specific mention to fish welfare in Denmark were only found in connection with an annual 1-day course organized by the Danish Aquaculture Association on the transport of live fish[70], and as a MSc program course at the Technical University of Denmark[71]. The lack of trained personnel and limited possibilities for training/education are often mentioned as among the key challenges in connection to efforts directed to improve the consideration of fish welfare in aquaculture (Pavlidis et al., 2023).

[68] https://foedevarestyrelsen.dk/dyr/dyrevelfaerd
[69] https://foedevarestyrelsen.dk/lovstof/vejledninger/oekologivejledningen
[70] https://danskakvakultur.dk/transport-af-levende-fisk/
[71] https://lifelonglearning.dtu.dk/aqua/enkeltfag/fiskefysiologi-og-velfaerd/

In official statistics reports, mortality is the only variable relatable to animal welfare. Mortality accounted for approx. 3,900 tons of fish in 2021, which constitutes close to 11% of the total fish production that year, in terms of weight. From the data per production type (Table 2), sea farms and inland farms with medium recirculation reported relatively low mortalities close to 7%. However, there is no discrimination between dead, escaped or discarded fish, there is no discrimination by species, there is no information about potential causes of death, and mortality is reported for juveniles and "larger fish" only. There is therefore a gap of knowledge about accurate mortality rates covering the whole production cycle, their variability across production sites and geographical area, or mortality causes in Danish fish farms.

Table 2. Total production and reported mortalities of fish in different types of farms in Denmark in 2021. Data derived from report from Danish Fisheries Agency, Fiskeristyrelsen[72].

Production data 2021 in tons	**Traditional farms**		**Low recirculation farms**		**Medium recirculation farms**		**High recirculation farms**		**Sea farms**	
	juvenile	large	juvenile	large	juvenile	large	Juvenile	large	juvenile	large
Used	371	4298	336	1350	1985	3096	3500	8897		8363
Dead	107	462	57	318	142	190	745	1289		578
% mortality from total (used + dead)	22%	10%	15%	19%	7%	6%	18%	13%		6%

Notes: "Used" includes fish used for export, consumption, and release to nature or put & take establishments.

It is important to note that the lack of legal requirements on welfare does not necessarily mean that the welfare of the fish is not taken care of. Keeping animals in a good welfare state is in the best interest of the farmers because of the generally positive correlation between welfare, health, appetite, and growth (Segner et al., 2019). Fish in poor welfare conditions will show reduced growth and potential mortalities that can rapidly generate important economic losses; in this regard Danish fish farmers are recognized as being good at reacting fast on detected welfare issues by immediately contacting a veterinarian (personal communication from Danish fish veterinarian). Also, current Danish legislation forces the fish farmers to focus on the environmental footprint of the farms by limiting their use of water and their discharges of nitrogen, phosphorous and organic matter. Better welfare status of the farmed fish will result in better growth and in a more efficient use of the feed given to the fish, thus reducing nutrient discharges and optimizing farm productivity within the assigned environmental discharge quotas. However, without specific requirements, fish rearing conditions on the farm can be flexible in terms of rearing unit design and size, water renovation, stocking densities etc., which generates uncertainty about their effects on the welfare status of the fish. Furthermore, there is no consideration in the regulations about the species or the developmental stages being farmed nor about the requirements for water quality inside the fish rearing units. Deciding and controlling these factors is up to the farmers, and rearing conditions are set up according to their experience and expertise.

Official statistics reflect that fish in Danish farms are produced under different production systems and farm types, including cages at sea and farms inland (either "traditional" or with different extent of

[72] https://fiskeristatistik.fiskeristyrelsen.dk/stat/Akvakultur_tab/Anvendelse_21_eng.html

water recirculation). The conditions provided for the fish, and the extent to which they vary within and among farm types is not reported, as neither is the welfare status in each case. This missing information would be critical to better understand welfare conditions in the Danish fish farming industry.

In Denmark, salmonid farming is not affected by infestations of sea lice, a parasitic crustacean, which constitutes one of the main welfare threats for Atlantic salmon farmed in Norway. Danish production of A. salmon is carried out in land based, closed RAS, where sea lice does not constitute a problem, and rainbow trout in Danish net pens is usually farmed at low salinities that do not favor the sea lice life cycle[73]. The status of each fish farm regarding the notifiable diseases is registered in the Central Animal Register (CHR)[74]. Most of the notifiable diseases are either absent in Denmark or occurring at a very low prevalence. Other non-notifiable diseases are present to a higher level and can impair the general health and welfare of the fish. There are no data reported on non-notifiable diseases in Denmark.

For the other species farmed in Denmark such as European eel, yellowtail amberjack and others, data available about their welfare status in Danish farms is also not available. Furthermore, fundamental knowledge about their welfare needs is poor (see Table 3). European eel has been a farmed species in Denmark for around three decades while the production of amberjack is reported since 2018[75]. Both species are farmed in RAS, but there are no reports available on current farming conditions and their adequation to the specific fish welfare needs.

Table 3. Number of studies available in the scientific database Scopus[76] when searching for the scientific name of a given species and "welfare" in article titles, keywords and abstracts. Searches were performed in February 2024.

Species/species group	Scientific name/group	Studies on welfare in Scopus
Rainbow trout	*Oncorhynchus mykiss*	223
Atlantic salmon	*Salmo salar*	463
European eel	*Anguilla anguilla*	21
Yellowtail amberjack	*Seriola lalandi*	10
Chars	*Salvelinus spp*	23
Pike-perch	*Sander lucioperca*	18
Striped bass	*Morone saxatilis/Morone chrysops*	9
Brown trout	*Salmo trutta*	27
European perch	*Perca fluviatilis*	9
Sturgeons	Acipenseridae	26

5.2 Conditions during transport

In Denmark, fish are transported mostly by road but also by sea, in connection with live fish exports and imports, transfers to abattoirs for slaughter, or transfers from inland facilities towards sea farms. Fish are generally transported in built-in tanks with aeration/oxygenation, but lacking filtration/treatment. A period of several days without feeding is usually kept before transport (European Commission, 2017).

[73] https://danskakvakultur.dk/havbrug/
[74] https://chr.fvst.dk/chri/faces/frontpage
[75] https://lfst.dk/fiskeriet-i-tal/akvakultur
[76] https://www.scopus.com/home.uri

As described in section 3.2, there are rules in place to control and inspect fish transport events at loading or unloading, that become stricter for longer transport in terms of documentation required and training of the involved personnel during the journey[77]. Inspection checks are directed at ensuring that the means of transport and conditions are adequate for the fish and that the animals are fit for the transport, but it is unclear how this is specifically determined for the transported fish, as there is no specific regulation for the rearing conditions of fish during transport. Water quality is ensured in terms of temperature and access to oxygen (through aeration/oxygenation), but likely not in connection to other variables such as pH, CO_2 levels, organic matter or nitrogenated compounds. Further, transport of fish usually requires processes of crowding, pumping and delivery to new water systems, for which there are no specific rules.

There is a clear gap of knowledge about whether current transport rules cover the welfare needs of the fish, and a critical lack of data about the welfare of the transported fish (conventional or organic) during and after transport, despite the current political focus on animal transportation. The DVFA annual reports on animal welfare in Denmark[78] mention fish during transport, but only in connection with the summaries of the police road controls, which show the total number of controls of road transports of different animals and the number of controls showing any incidence in connection to current Regulations (see Table 4). However, the reports show no information of any kind in connection to the welfare status of fish during transport.

Table 4. Number of official inspections reported in yearly reports on animal welfare from DVFA[79].

Year	Total inspections of animal stables with CHR	Inspections of fish stables with CHR	Total police road controls of animal transports	Police road controls of fish transports
2022	1195	0	898	4
2021	835	0	925	12
2020	1824	0	1005	5
2019	1439	0	996	4
2018	1623	0	891	0
2017	1134	0	917	6
2016	1158	0	846	16
2015	1786	0	1095	7

Note: Table does not include numbers of more in-depth welfare controls during transport or at slaughterhouses, that are reported for other farmed animals, but not for fish in any of the annual reports.

5.3 Conditions at slaughter

Farmed trout in Denmark are usually slaughtered either on-farm or on abattoirs after transport and a waiting period (European Commission, 2017, 2018). Most used slaughter method is electrical stunning followed by killing by throat cut, or asphyxia on ice (in some farms), with different consideration on fish welfare according to WOAH and their OIE guidelines[80], as asphyxia on ice is considered a non-humane slaughter method in fish. As there are no rules or reports about specific methods for killing farmed fish in Denmark, it is unknow to which extent good welfare practices are in place nationally

[77] https://danskakvakultur.dk/transportkursus-baggrund-og-lovgivning/
[78] https://foedevarestyrelsen.dk/dyr/dyrevelfaerd
[79] https://foedevarestyrelsen.dk/dyr/dyrevelfaerd
[80] https://www.woah.org/en/what-we-do/standards/codes-and-manuals/aquatic-code-online-access/?id=169&L=1&htmfile=chapitre_welfare_stunning_killing.htm

in regards fish welfare at slaughter. The DVFA yearly reports on animal welfare in Denmark[81] do not mention any control or provide any information about the welfare status of fish at slaughter.

In summary, even for organic aquaculture, it is not possible to assess from available information (data and/or reports), whether Danish conditions provide a farming environment according to the welfare needs of the different fish species as reported in EFSA, WOAH, RSPCA or other recommendations. No reference values for input-based indicators are stipulated, and no outcome-based indicators are measured or reported to assess the actual status of the fish.

5.4 Potential tools to promote and assess welfare in Danish trout fish farming

There are no adopted standards on fish welfare in Denmark in term of rules for the use of fish in fish farming, and no regulations on surveillance programs or on methodological tools to assess and monitor fish welfare. Current reports on welfare only include data on mortality, and without any consideration of mortality causes. The use of animals on the farms, during transport, or at slaughter is only governed by very general rules that do not provide guidance about the needs of the fish, neither generic nor species-specific.

Welfare needs and conditions promoting welfare

For the main aquaculture species in Denmark, rainbow trout, there is abundant fundamental scientific information on their welfare needs, and different guidelines, recommendations and even welfare standards are available. The current scientific background seems to be enough for the potential implementation or adoption of certain standards for trout welfare, either as recommendations or as specific aquaculture regulations for this species. For Atlantic salmon, the case is similar, as there is also a good base of scientific knowledge and specific documents available on good practices, recommendations, etc. for different production systems.

Comprehensive documents available for rainbow trout and Atlantic salmon, already mentioned in section 4.3 include:

- The FISHWELL project manuals from Nofima (Norway), reviewing review the welfare needs at different production systems (RAS, flow-through, cages) and at different operations (on-farm, during transport, at slaughter, etc.) (Noble et al., 2018, 2020).
- The RSPCA welfare standards providing recommendations for the conditions to be provided to the fish on farm, during transport and at slaughter (RSPCA, 2020, 2021).
- The European Food Safety Administration (EFSA) publications reporting specific husbandry welfare needs for Atlantic salmon and trouts (rainbow trout and brown trout) (EFSA, 2008a, 2008e). EFSA also published reports for welfare consideration during stunning and killing of these two species (EFSA, 2009d, 2009a).

For European eel, detailed info on welfare needs of the species on farm and at slaughter can also be found in EFSA publications (EFSA, 2008d, 2009c).

For the rest of species farmed in Denmark, only limited information about their welfare needs is available. However, some generic guidelines and principles for fish welfare are available, that might be used when detailed specific knowledge on species welfare needs is lacking. Those include some recommendations at EU level: *Recommendations concerning farmed fish* from the *Standing Committee of the European Convention for the Protection of Animals kept for Farming Purposes, adopted by the*

[81] https://foedevarestyrelsen.dk/dyr/dyrevelfaerd

Committee on 5 December 2005[82]. Other relevant documents include the "Guidelines on water quality and handling for the welfare of farmed vertebrate fish" published by the Own Initiative Group on Fish from the EU Platform on Animal Welfare (EU Platform on Animal Welfare Own Initiative Group on Fish, 2020), the "Recommendation on fish welfare in live fish Transport" published by the Aquaculture Advisory Council(The Aquaculture Advisory Council (AAC), 2022), or the recommendations for stunning and killing[83] and for transport[84] from the Aquatic Animal Health Code of the WOAH (World Organization for Animal Health, 2023).

Welfare assessment tools and protocols

For a number of fish species, suggestions for welfare indicators and for complete welfare assessment schemes (see also section 3.2) are also available and could probably be adopted (or adapted) for surveillance purposes. Currently, there is no widespread standard in the adoption of specific welfare schemes, and there is very limited publicly available data on application of any of them in fish farms. For rainbow trout and A. salmon, the FISHWELL manuals (Noble et al., 2018, 2020) provide recommendations for specific welfare indicators to be used in different production systems (see examples in Figure 8, Figure 9 and Figure 10) and review their advantages and disadvantages. Systematic models, based on scoring a number of welfare indicators and applicable directly at farm level, are also available. They are intended to provide an output score for fish welfare that can be used to compare welfare status of fish on different farms. However, those models are species and production system-specific, and their use has not yet become widespread, so they would likely need to be further validated for their potential use as a routine tool for welfare assessment in farmed fish. As commented before, those include the fWEI model for rainbow trout in flow-through systems (Weirup et al., 2022), the salmon welfare index model 2.0 (SWIM 2.0) for Atlantic salmon in sea cages (Pettersen et al., 2014), or the generic model framework MyFishCheck (Tschirren et al., 2021).

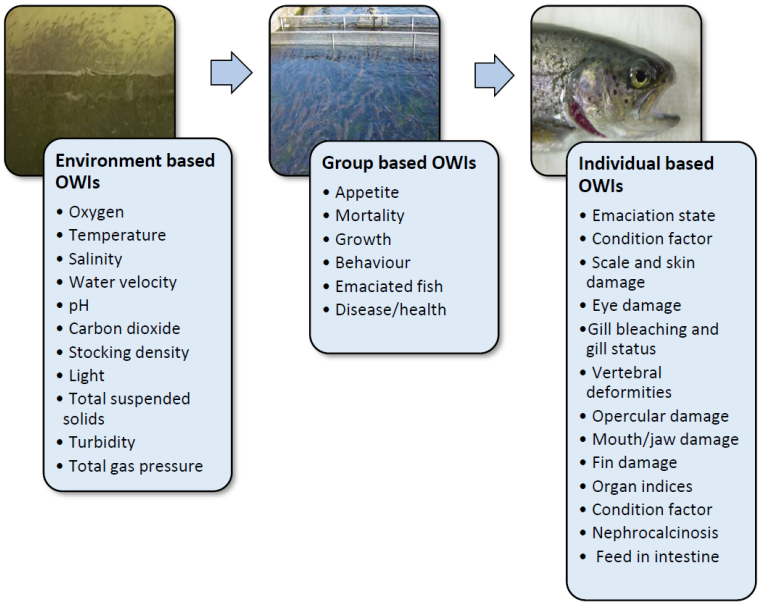


Figure 8. Suggested welfare indicators to be used for welfare assessment of rainbow trout in land-based flow-through farms. Extracted from (Noble et al., 2020) (Fig 1.3-1).

[82] https://www.coe.int/t/e/legal_affairs/legal_co-operation/biological_safety_and_use_of_animals/farming/Rec%20fish%20E.asp#TopOfPage
[83] https://www.woah.org/en/what-we-do/standards/codes-and-manuals/aquatic-code-online-access/?id=169&L=1&htmfile=chapitre_welfare_stunning_killing.htm
[84] https://www.woah.org/en/what-we-do/standards/codes-and-manuals/aquatic-code-online-access/?id=169&L=1&htmfile=chapitre_welfare_transport_farm_fish.htm#chapitre_welfare_transport_farm_fish_0

For E. eel and the other species farmed in Denmark, such kind of detailed protocols or models for welfare assessment are not yet available. In some cases, it might be possible to adapt models developed for salmonids to other species (Yavuzcan Yildiz et al., 2021).

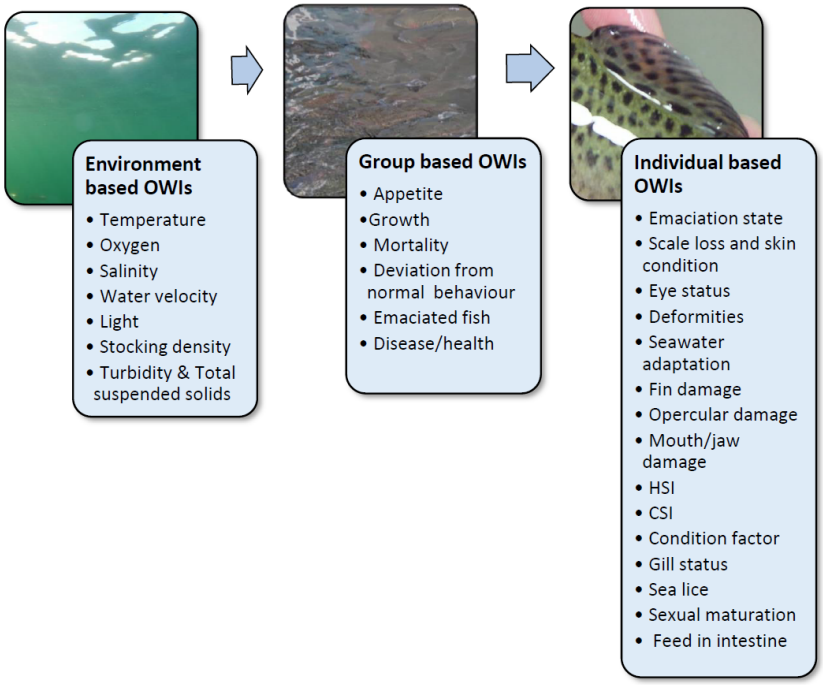


Figure 9. Suggested welfare indicators to be used for welfare assessment of rainbow trout in sea cages. Extracted from (Noble et al., 2020) (Fig. 2.3-1).

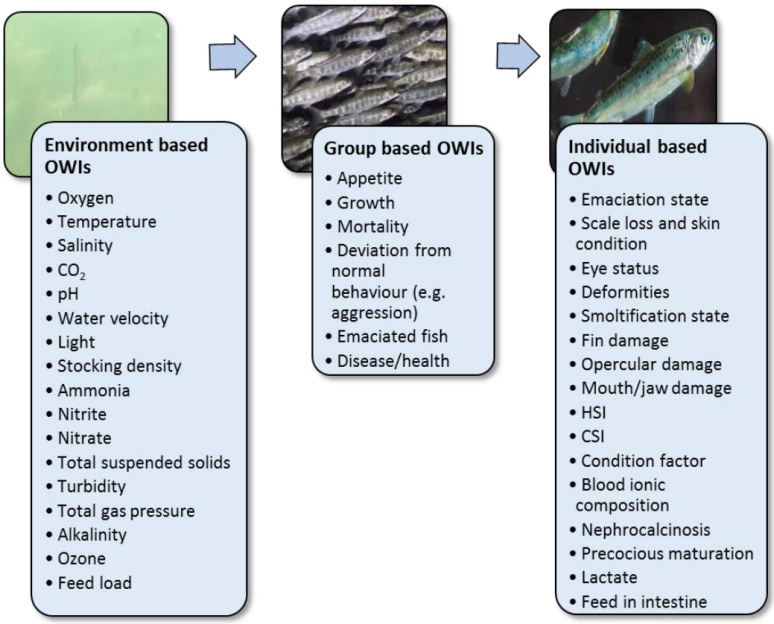


Figure 10. Suggested welfare indicators to be used for welfare assessment of A. salmon in RAS systems. Extracted from (Noble et al., 2018) (Fig. 2.3-1).

Equally important in assessing welfare would be reporting the obtained data. There is a clear need to generate open-access databases for welfare data on fish welfare indicators measurements, but also best practices, methods used, etc., in line with ongoing efforts at EU level to increase FAIR data for

animal welfare. Open databases on welfare are starting to be available for other farmed animals, and the need to promote transparency on animal welfare in the food production sector has been highlighted (Blokhuis et al., 2003).

6. Conclusions: Knowledge gaps and recommendations

In Danish fish farming, consideration of fish welfare is low. Current regulatory framework for the welfare of farmed fish is unspecific and does not provide concrete binding rules regarding:

- specific acceptable levels/standards for the conditions provided to the fish in relation to production factors, water quality parameters and other variables known to affect fish welfare during production on-farm, during transport events, or at slaughter.
- methodology for assessment and monitoring of fish welfare in connection with farming activities.
- requirements for welfare surveillance and reporting.

The regulatory state in Denmark is very much in line to that reported at EU level in the recent report by Pavlidis et al. (2023). In that report, it is suggested that the current lack of specific binding rules on fish welfare likely derives from the combination of insufficient scientific evidence and the large diversity of the aquaculture sector in terms of species, production systems, and locations.

There is a gap of knowledge on the conditions provided to the fish in Danish farms, as regulations are mostly controlling the discharge of nutrients to the environment, and do not provide rules on input-based welfare indicators associated to water quality, rearing environment, operational practices, etc.

More importantly, there is gap of knowledge about the welfare status of fish in Danish farms in terms of outcome-based indicators. The only outcome variable relatable to welfare that can be extracted from official statistics is fish mortalities. Mortality is a weak indicator of animal welfare, particularly when the cause is not reported and when there is no information about the welfare of the fish that survive (Noble et al., 2018). Without proper welfare monitoring tools and welfare data reporting, it is not possible to know whether Danish fish farming is complying with generic rules on animal welfare, such as those imposed by the Danish Animal Welfare Act. A periodic assessment of welfare indicators would be needed to assess the baseline status of farmed fish, and to detect trends on its evolution, which could be used for management and development of corrective measures if needed. Furthermore, the availability of data series on fish welfare collected on-farm, during transport, and at slaughter, along with relevant production variables, would be valuable for animal welfare researchers in investigating strengths and weaknesses in connection to welfare and productivity optimization in fish farming.

Knowledge about welfare needs of some of the species farmed in Denmark is limited. Knowledge on how certain production factors and variables affect the welfare of farmed fish is also limited. However, there is good knowledge about the welfare needs of certain species in connection to different production factors, which has allowed the development of recommendations for optimized rearing conditions, fish handling and welfare assessment in some species such as rainbow trout or Atlantic salmon, of aquaculture relevance to Denmark. At least for those species, information available looks mature enough to allow the adoption of either standards/recommendations as “soft” welfare rules or the adoption of regulations on minimum requirements as “hard rules” (Pavlidis et al., 2023).

In their 2023 report about farmed fish welfare in the EU, Pavlidis and collaborators produced a series of policy recommendations to overcome the current issues in connection to animal welfare protection and promotion in EU aquaculture. The recommendations set out are most relevant for the Danish aquaculture sector as well.

Main recommendations in Pavlidis' report include:

- Encourage societal awareness on fish welfare and support multi-disciplinary research on welfare of farmed fish.
- Support fundamental research on the welfare needs of farmed fish species in connection with the farming environment, for specific production systems, operational practices (crowding, transport, slaughter, etc.) and fish developmental stages.
- Support research and development of fit-for-purpose tools for welfare assessment such as species-specific operational welfare indicators, welfare scoring systems, and technology to monitor and assess fish behavior on-farm.
- Develop educational tools and promote education and training of key personnel (veterinarians/health professionals, farmers) in relation to fish welfare needs and the use of fish welfare assessment tools.
- Promote research and development and industrial adoption of new technology to improve fish welfare, such as tools for continuous and/or automatized monitoring of fish welfare, or for humane slaughtering.
- Improve legislative framework to ensure the provision of good welfare conditions for farmed fish and its surveillance, considering species-specific needs.

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