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Implementation of the European perch (*Perca fluviatilis*) into MyFishCheck

Bachelor thesis

by
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Abstract

Fish welfare within aquaculture suffers from the fact that regulations and legal requirements for animal welfare primarily apply to terrestrial animal husbandry. However, fish welfare plays a major role in fish husbandry, and it has been increasingly recognized since the early 2000's that fish can feel pain and need to be protected by law. In order to grant certain standards of welfare in husbandry the ability to measure and monitor welfare is key. For this, fish farmers need assistance and tools that are practicable and can be incorporated into their daily routines. MyFishCheck is such a tool and was developed by the Aquaculture Systems Research Group at the ZHAW in Wädenswil to support fish farmers in monitoring fish welfare. MyFishCheck is a model based on the scoring of different parameters, which are decisive for fish welfare, to assess the current welfare status of fish. The corresponding app facilitates the assessment for fish farms as they can enter the data and analyse the results digitally. The app is built in a modular way to ensure that more fish species, languages, or parameters can be added. This thesis had two goals, first, the implementation of the European perch (*Perca fluviatilis*) into the model and the app, and second, the development of a Standard Operating Procedure (SOP) on how such a species implementation is to be carried out. A complete implementation of the European perch into MyFishCheck was successfully carried out and its individual steps were documented. The parameters and their weighings within MyFishCheck were adapted to the needs of the European perch and justified based on a comprehensive literature search. A user-friendly SOP was created to facilitate future implementations of additional fish species in a standardised way, allowing for the continuous increase of the use and range of MyFishCheck.

Content

1. Introduction

Already two centuries ago, some academics have argued that animals can feel and suffer (Bell, 1792; Hume, 1777). This laid the foundation for a constantly growing awareness of animal welfare, within animal husbandry. In the early 2000s, animal welfare regulations were put forward in terrestrial livestock farming (Legislation Gov. UK, 2006) and to this day, laws and regulations for welfare of animal husbandry are being developed further. However, this development has not progressed to the same extent in all parts of animal husbandry. Compared to terrestrial animal husbandry, aquaculture has been left out of this development a long time (Bauer, 2018). However, since studies in the early 2000s examining pain perception in fish, it was increasingly assumed that scientific evidence could not rule out potential pain perception in fish (Sneddon, 2003b, 2003c). It was because of such publications that the public opinion changed and that today the pain perception in fish is accepted and higher standards for fish welfare in animal husbandry are therefore needed (Kiessling et al., 2012). The setting of such standards on how to measure, evaluate, assess, and document fish welfare is challenging and an on-going process in the field of aquaculture.

1.1. Aquaculture in Switzerland

While the per capita consumption of fish and crustaceans has remained constant in Switzerland over the past ten years, the demand for edible fish has steadily increased due to the population growth (BFS, 2022; SFV, 2019). Excessive consumption can have negative consequences for the environment. For example, overfishing in waters abroad is a major problem as it endangers wild stocks (Kench & Owen, 2015) and disturbs the ecological balance permanently and sometimes irreversibly (Akita et al., 2022; Ellingsen & Aanondsen, 2006; Valentine & Heck, 2005). To protect the environment, artificial husbandry, i.e., aquaculture, can be part of the solution (Fraga-Corral et al., 2022). But, fish farming needs to improve itself to become more environmental sustainable in the future to minimize the negative environmental impact of fish consumption (Boyd et al., 2020; Carballeira et al., 2021). In Switzerland people become aware of the advantages of aquaculture and hence the demand for high-quality and sustainable fish is increasingly met by farmed fish. In 2016, the number of fish produced in Switzerland in aquaculture systems exceeded that of commercial fisheries for the first time (BFS, 2022). Nevertheless, aquaculture in Switzerland still has great potential for growth and development. Compared to other types of animal husbandry, fish farming is still in a pioneering phase. Especially, applicable methods to evaluate health and welfare of the farmed fish are largely missing. Fish welfare has been ignored for a long time and not put on equal footing with the terrestrial farming of mammals

(Bauer, 2018). These farm animals can evoke empathy in humans more quickly than supposedly mute fish in fish farms through more similarities, such as expressing pain through screaming or shouting.

1.2. Animal welfare

With only a few applicable tools available for assessing fish welfare and lagging legislation, fish farms can rely on research findings and known definitions of animal welfare. Furthermore, there are two commonly agreed-upon frames of definitions for animal welfare. The first well-known concept used in aquaculture is represented by the five freedoms for animal welfare. The five freedoms were first established by the Farm Animal Welfare Council in the United Kingdom in the 1970's and grant an animal the following:

- Freedom from hunger and thirst
- Freedom from environmental challenges
- Freedom from pain, injury, and disease
- Freedom to express normal behaviour
- Freedom from fear and distress

The advantage of having defined these five freedoms is that the model is practical, since it outlines achievable goals. However, the five freedoms model is often criticized when it comes to fish welfare because it suggests that the optimum environment is without stressors. The second concept can be divided in three broad categories. **1)** Feeling-based definitions incorporate emotional states of fish. Here, fish welfare can be improved by reducing stress and fear while increasing positive experiences such as social components adapted to the fish species. **2)** Function-based definitions of fish welfare focus on the ability of the fish to cope with and function within their current environment. In this case, fish welfare can be improved by understanding and meeting the fish's physiological needs so that fish can achieve good physical health. **3)** Nature-based definitions emphasize the natural environment of the fish. Increasing the possibility for a fish to express its natural behaviour and experience natural surroundings improves its welfare (E. Branson, 2008; Cerqueira & Billington, 2020). These definitions are an important part of understanding and improving standardised fish welfare.

Despite such concrete definitions and findings, fish farms are still facing the challenge of measuring and evaluating fish welfare. Nevertheless, these definitions can help fish farms assess fish welfare for example by checking parameters that influence these definitions of welfare.

1.3. Fish welfare

Fish in fish farms are often kept in balanced or homogenous conditions to minimize stress factors and improve fish welfare. However, this approach can result in linear stress-related properties and stress-loads for the fish, which can have a negative impact on their welfare (Conte, 2004). Research has shown that fish need certain challenges in order to achieve optimal well-being and stability, a process known as allostasis (Berillis, 2017; Cerqueira & Billington, 2020). Allostasis is when temporary stressful situations provide certain advantages to an animal, allowing them to achieve new stability and resilience against future stress through physiological and psychological changes.
Welfare is an important consideration in animal husbandry, but it can be difficult to collect good quality data on the topic. Fish farms face additional challenges in this regard due to the lack of tools for measuring and evaluating fish welfare, making it difficult for them to meet legal requirements and share information with other fish farms.

1.4. Fish welfare assessment

Raising societal requirements for a higher standard of welfare on fish husbandry makes standardised documentation of fish welfare and operation procedures within fish farms needed (BAFU, 2021). Therefore, the research group for aquaculture systems at the Zurich University of Applied Sciences has taken on the problem in a project. MyFishCheck was created, as a tool to assess fish welfare in aquaculture, for fish farms to use within their own company to improve fish welfare (Tschirren et al., 2021). MyFishCheck is a model developed for smaller fish farms and can be adapted to individual needs to ensure its practicability and user-friendliness. The model allows to assess scientifically collected and relevant parameters that influence fish welfare. Based on a scoring the model then calculates intuitive welfare grades from these parameters. The MyFishCheck model was implemented in two formats suited for different users. An Excel format that is particularly suited for researcher with specific needs and good skill in Excel. For fish farmers there is a MyFishCheck app for the mobile phone that enables the use of the MyFishCheck model directly and easily. The model and app have both been developed in a modular way to facilitate future adaptions to new knowledge. Due to its adaptability, MyFishCheck is designed to be complemented with new fish species.

1.5. Goals within this thesis

Within this bachelor thesis, three main goals are reached. First, the implementation of the European perch (*Perca fluviatilis*) into the MyFishCheck model. Through comprehensive literature research, parameters, intervals, and their weights within MyFishCheck are adjusted to the European perch. Second, it is outlined how the fish species established within the model can be implanted into the mobile phone app. Third, a Standard Operating Procedure (SOP) is created which enables researchers in the future to integrate a new fish species and new information into the MyFishCheck model relatively independently and based on scientific literature research and professional experience, and thus making the model more comprehensive.

1.6. European perch (*Perca fluviatilis*)

The European perch is a popular fish in Switzerland and is increasingly farmed in recirculating aquaculture systems. The species is a representative of the order of the Perciformes and belongs to the perch family (*Percidae*). Like other fish species in this family European perches are very flexible, adaptable and robust (SFV, 2019). Because of these properties and due to its popularity as a food fish, the European perch is well suited for husbandry in fish farms. The demand for regionally produced and domestic fish is constantly increasing in Switzerland, particularly the demand for European perch. This trend is confirmed by the emergence of more and more fish farms breeding and growing European perch in Switzerland. In 2016, industrial fish producers in Switzerland produced European perch with a slaughter weight of 310 tonnes, which puts the species in second place among the industrially produced edible fish in Switzerland, behind trout (Hidber et al., 2018). For this reason, it is important to take a close look at the European perch regarding fish welfare and therefore to implement it in MyFishCheck.

2. Methods & Results

Due to the particular requirements of the outputs from this thesis the methods and results part are specifically arranged.

- In chapter 2.1. the functionality of the MyFishCheck model and its structure are outlined, to provide the necessary basis.
- Chapter 2.2. entails the parameters adaptation for the European perch based on the literature review.
- In chapter 2.3. a short description of the procedure for the digital implementation into the app is given.
- Chapter 2.4. then describes the development of a SOP for the implementation of other fish species into the model.

2.1. MyFishCheck

The MyFishCheck model allows users to make welfare assessments for specific fish species based on 80 parameters. The core principle of the model is a scoring system of these parameters to allow a mathematical unification of the different units. The functioning of the model can be outlined in five steps: modules, parameter scores, score weight, parameter weights, and equation.

2.1.1. Modules

To facilitate the use of the model, the 80 parameters are summarized in five different modules originally named **Farm management**, **Water quality**, **Fish group behaviour**, **Fish external appearance**, and **Fish internal appearance** to allow independent assessments for each module based on their measuring methodology and dependencies. In the course of the ongoing development of the second release of the app, the modules were renamed to be more intuitive for the user:

- **Farm management**
- **Water quality**
- **Fish behaviour**
- **Fish morphology**
- **Fish anatomy**

2.1.2. Parameter scores (PS)

In MyFishCheck, all parameters are standardised using a scoring system. First, all measurements and input values fall within certain intervals. The number of intervals within each module of MyFishCheck may vary, depending on how well the intervals can be determined based on existing literature and experience. While a higher number of intervals leads to more accurate results, it becomes more difficult to scientifically justify the limits of these intervals as the number increases. Each interval is assigned a parameter score (PS) based on its impact on fish welfare. The PS is a number from 0 to -1, with 0 indicating little or no negative influence on fish welfare and -1 indicating a clear negative impact.

2.1.3. Score weights (SW)

In the model, all scores are weighted to ensure that the parameters with a negative influence on welfare are weighted more. The score weights (SW) are expressed as numbers from 1 to 5 in all modules in MyFishCheck. A SW of 1 would be allocated for parameter intervals that inflict low or no stress-inducing effect. A SW of 5 would be allocated for parameter intervals that inflicts strong, long-term, or recurrent stressors.

2.1.4. Parameter weights (PW)

Within the MyFishCheck model, all parameters are weighted according to their relative importance. The parameter weights are expressed as numbers from 1 to 5. Parameters were weighted according to their importance through a comprehensive and independent evaluation by experts. A parameter with a PW of 5 has a higher or more immediate and severe impact on the welfare of fish than a parameter with a PW of 4. A PW with the number 1 represents the relative lowest importance of a parameter in relation to its influence on fish welfare. Half numbers are assigned to for the PW within MyFishCheck, therefore values such as 1.5 or 4.5 are possible.

2.1.5. Equation for module grades (MG)

Per module the values of the weighted parameters are summed up, normalised, and offset with an equation (Eq. 1). In order to evaluate welfare of fish intuitively, the model calculates inserted values for the parameters which were entered. The grades that result from an evaluation within a module are divided into four different coloured categories in the MyFishCheck model.

- A grade between 1 and 0.75 results as **good welfare** which indicates that welfare is given according to the current knowledge the model is based on. Therefore, fish are likely to experience good welfare.
- A grade between 0.75 and 0.5 results as **acceptable welfare** which indicates that welfare is given according to the current knowledge the model is based on, but the welfare is improvable.

- A grade between 0.5 and 0.25 results as **poor welfare** which indicates that welfare is affected negatively and therefore long-term impairments are expected.
- A grade between 0.25 and 0 results as **critical welfare** which indicates that welfare is severely compromised and therefore short- and long-term impairments are expected.

$$MG_j = \left(\frac{\sum_i PS_i \times SW_i^{SWE_i} \times PW_i^{PWE_i}}{\sum_i SW_i^{SWE_i} \times PW_i^{PWE_i}} + 1 \right) \times 100$$

Equation 1: The corrected and adapted equation used in the MyFishCheck model to calculate the module grades (MG); SWE and PWE are additional calibrating exponents of SW and PW. (Tschirren et al., 2021)

In the course of the ongoing development of the second release of the app, the equation is adapted to results in a percentage (0-100 %) instead of a proportion (0-1) as this is more intuitive for the app users.

2.2. Implementation of the European perch into the MyFishCheck model

The implementation process of the European perch into the MyFishCheck model consisted of several steps. After researching the literature on the needs of the European perch, the changes that had to be made to the parameter intervals within MyFishCheck were carried out. Changes were inserted directly into the given PowerPoint format. The PowerPoint format makes sense because it is easy to leave additional references to the literature with comments and because this format allows the programmer in the implementation process an easy and efficient way to pull out the necessary data for MyFishCheck.

In the following subchapters, 2.2.2 to 2.2.6, each module within MyFishCheck will be covered with its parameters and intervals as well as its scores and weights. The importance of the individual parameters within the five modules will be justified and underpinned by the results of the previous literature research.

2.2.1. Literature research process of European perch

To Implement the European perch into MyFishCheck, a comprehensive literature research was carried out to find all the parameters with their influence on fish welfare. This literature research included and went beyond the parameters already implemented within MyFishCheck. It was very important to not just focus on the already implemented parameters but look out for every single influence on fish welfare which is maybe species-specific too. All differences in parameters and weights between the already implemented and the new fish species needed to be adjusted for the implementation process. Attention was paid to which parameters within MyFishCheck are relevant and which are not relevant for assessing welfare. It was important to get a general overview of the European perch from a variety of new and older sources. Inconsistencies or discrepancies in the assessment of all relevant parameters were checked through comprehensive literature research. The parameters were checked regarding their influence, whether changes in the weighting of parameter score, parameter weight, and score weight had to be made within MyFishCheck in order to achieve an optimal result with MyFishCheck.

The literature search was conducted on Web of Science (September 2022) and included scientific articles, documents, books, and publications. With keywords like fish welfare, animal welfare, fish perception of pain, assessing fish welfare, European perch in fish farms, 7700 articles were displayed in Web of Sciences. Other search engines such as Science direct, PubMed, and the ZHAW University Library were used too for literature research. A total of 238 articles were considered, of which 87 were decisive for the implementation of the European perch. The references relevant for each parameter are indicated in the parameter tables in the appendices A-E respectively.

Zotero was used as a reference management software and all articles found were stored in one online library with access for the whole team. The key information from the articles relevant for this work were managed in an Excel file for a better overview and facilitate discussions. Final values for parameter intervals as well as their references and remarks were then transferred to the parameter table template in the PowerPoint format.

2.2.2. Farm management

The module farm management contains parameters that describe the fish farm with its management and procedures. It is the only module that deals directly with the operators of a fish farm and their working standards and procedures. This module contains parameters that have a major impact on fish welfare, as these parameters are usually crucial for a good basis for the actual operation of a fish farm, such as the parameters "personnel training" and "emergency plan". Personnel training is directly related to the highest level of specialist training of the responsible person within a fish farm and has an impact on their working methods and thus on fish welfare. The higher the training of the responsible person, the higher the chance of more specialist knowledge and correct handling of the system and the fish. Similarly, a comprehensible and sophisticated emergency plan can possibly save the entire stock of fish in an emergency situation. Many of the parameters within this module depend on each other or form an important basis for the other modules within MyFishCheck. For example, the parameter "daily checks" helps to ensure that the entire modules water quality or fish behaviour are subject to sufficient assessment and clean documentation.

Parameters

Within the module 18 parameters exist and were checked against a comprehensive literature review and, if necessary, adapted to the needs of the European perch. The parameters treatment journal, target value sheet, emergency plan, hygiene concept, mortality documentation, and biomass documentation include important documentation within the working process. Further, personnel training, daily check, disturbances, predator protection, plant cleanliness, sorting, and slaughter include key working standards of the fish farm. Additionally, stocking density, feed interval and rate, feed type, ambient light, and tank light incorporate general conditions the fish are held in. According to the literature research on the European perch, all these parameters are necessary, and no additional parameters were added. While the first two groups of parameters are not species-specific, the third group is and hence potential adaptations to the European perch in terms of the intervals were considered carefully.

Intervals

Each parameter within the farm management module works with three intervals. The literature research did neither give any reason to change the number of intervals per parameter nor the interval boundaries of any of the 18 parameters. This includes the more species-specific parameters as the intervals were either in line with the previously incorporated pikeperch (stocking density) or were formulated in a flexible way (light and feed). It has to be mentioned that some of the parameters are based on legal requirements (personnel training, daily checks, treatment journal, mortality documentation or stocking density) and hence their intervals are based on Swiss legislation.

Score

To unify all the different parameters the intervals are scored. The best interval has a parameter score (PS) of 0 meaning the parameter has no negative impact on fish welfare. The second interval has a PS of -0.5 indicating a slight negative impact on fish welfare. The third and last interval has a PS of -1 as it has a considerably negative impact on fish welfare. As there were no changes to the number of intervals, there were no adaptions to the scoring system needed.

Weights

The first version of the MyFishCheck model incorporated parameter weights that were defined with an extensive expert survey. During the literature research no reasoning was identified to rectify any changes in these weights.

2.2.3. Water quality

Within the module water quality are the parameters which describe the quality of the water in the system of the fish farm. As the water is the imminent main environment of the fish it is imperative for the health and welfare of the animals. Notice that the module water quality is the only module which works with empirical values of the parameters and the parameter intervals are very specific for each fish species. All parameters make a significant contribution to ensuring and improving fish welfare and are all relevant, practicable and reliable in relation to collecting and/or ensuring fish welfare. Compared to the other four modules, this module is the most species-specific and hence the interval limits were adapted to the needs of the European perch. Some of the parameters within this module are interdependent (Pohling, 2015) such as oxygen saturation (based on temperature and oxygen concentration) and ammonia (based on ammonium and pH), which makes the definition of individual optima challenging.

Parameters

Within the module 14 parameters exist and were checked against a comprehensive literature review and, if necessary, adapted to the needs of the European perch. Those parameters include the very basic physical aspects, i.e., water temperature and velocity as well as total suspended solids and total gas pressure. Further, the main chemical parameters including oxygen concentration, oxygen saturation, carbon dioxide, pH, carbon hardness, electrical conductivity. Furthermore, the key nitrogen parameters are included, i.e., ammonium, ammonia, nitrite, and nitrate. According to the literature research on the European perch, all these parameters are necessary, and no additional parameters were added.

Intervals

Each individual parameter within the water quality module works with four intervals, which have been adapted to the needs of the European perch based on comprehensive literature research and empirical values. The temperature ranges were adapted to the known natural habitat of the perch and various references indicating better health and growth at higher temperatures (Christensen et al., 2020; Ekstro

& Pichaud, 2017; Gebauer et al., 2021; Jensen et al., 2017; Knaus, 2012; Wolter, 2018). Accordingly, the parameters oxygen and oxygen saturation the interval limits were lowered compared to the rainbow trout (Baekelandt et al., 2018; Grapci-Kotori et al., 2019; Klontz, 1991; Schäfer et al., 2021; Stejskal et al., 2009). The interval limits for the parameter nitrate were raised compared to rainbow trout based on habitat preferences and no references for nitrate sensitivity (Knaus, 2012; Schram et al., 2010; Steinberg, Zimmermann, Stiller, et al., 2018; Zienert & Heidrich, 2005). Further, the limits of the optimum interval for the parameter pH were widened (Altinok et al., 2006; Christensen et al., 2020; Gebauer et al., 2021; Klontz, 1991; Rask, 1984; Zienert & Heidrich, 2005). It has to be mentioned that some of the parameters are based on legal requirements (oxygen, oxygen concentration, ammonia, nitrite and pH) and hence their intervals are not only based on the literature research but ensured to be in line with Swiss legislation. The intervals have been redefined directly in the original PowerPoint files by using two numbers each defined for a lower and upper value in which the interval is located. The interval thresholds could thus be documented in the PowerPoint files for each of the parameters.

Score

To unify all the different parameters the intervals are scored. The best interval has a parameter score (PS) of 0 meaning the parameter has no negative impact on fish welfare. The second interval has a PS of -0.33 indicating a slight negative impact on fish welfare, followed by the third with a PS of -0.66. The fourth and last interval has a PS of -1 as it has a considerably negative impact on fish welfare. As there were no changes to the number of intervals, there were no adaptions to the scoring system needed.

Weights

The first version of the MyFishCheck model incorporated parameter weights that were defined with an extensive expert survey. During the literature research no reasoning was identified to rectify any changes in these weights.

2.2.4. Fish behaviour

The module fish behaviour contains parameters that describe the dynamics and behavioural patterns of a fish shoal. The individual parameters are used to determine whether the fish behave conspicuously or unusual. All characteristics of the fish within its group, which can be determined without hurting the fish and sometimes even without touching the fish or interrupting them. All parameters contribute significantly to ensuring and improving fish welfare and are all relevant, practicable and reliable in relation to the collection and/or ensuring fish welfare. Some of the parameters within this module are interdependent, for example "aggression" and "skin injuries" and have a direct impact on fish welfare. In order to collect data for this module, it is possible to work with artificial intelligence in connection with a camera to record behavioural patterns.

Parameters

Within the module 20 parameters exist and were checked against a comprehensive literature review and, if necessary, adapted to the needs of the European perch. The parameters aggression, territoriality, scratching, apathy, isolation, surfacing, air gulping, ventilation rate, and fleeing evaluate how the fish behave within the shoal. Further, fin position, balance, body colour, feeding, jaw deformations, gill cover deformations, spinal deformations, eye injuries, skin injuries, fin injuries, and fungal infections assess possible injuries and diseases within a shoal. According to the literature research on the European perch, all these parameters are necessary, and no additional parameters were added.

Intervals

Each parameter within the fish behaviour module works with six intervals. During the literature research no reasoning was identified to rectify any changes in these intervals.

Score

To unify all the different parameters the intervals are scored. The best interval has a parameter score (PS) of 0 meaning the parameter has no negative impact on fish welfare. With each lower rating level with a higher negative impact on fish welfare, the PS decreases by 0.2 points until the lowest rating level with a PS value of -1. The sixth and last interval therefore has a PS of -1 as it has a considerably negative impact on fish welfare. As there were no changes to the number of intervals, there were no adaptions to the scoring system needed.

Weights

The first version of the MyFishCheck model incorporated parameter weights that were defined with an extensive expert survey. During the literature research no reasoning was identified to rectify any changes in these weights.

2.2.5. Fish morphology

The module fish morphology contains parameters that describe an average of external physiological aspects of an individual fish. Not the fish as an individual, but the average results of 3-10 fish are then entered into the MyFishCheck model. The module contains parameters that describe an average of external physiological aspects of fish. All of these parameters deal with deformations and injuries on the outside of the fish body, contribute significantly to ensuring and improving fish welfare and are all relevant, practicable and reliable in relation to the collection and/or ensuring fish welfare. Additionally, the module contains the parameter body condition factor with a species-specific parameter which is calculated from the length and the weight of a fish. In order to collect data for this module, it is possible to work with artificial intelligence in connection with a camera to record i.e., illnesses and injuries.

Parameters

Within the module fish morphology 18 parameters exist and were checked against a comprehensive literature review and, if necessary, adapted to the needs of the European perch. The parameters can be put in different groups. The parameters pectoral fins, ventral fins, anal fin, caudal fin, and dorsal fin determining injuries or lacking fish fins. Cataract, eye injury, and exophthalmia are parameters which deal with the condition of the eyes. Skin alterations, skin fungus, and skin injury are parameters which deal with conditions of fish skin. The parameters body condition factor, spinal deformation, jaw deformation, mouth injury, mucus pathogens, gill cover, and gills deal with further important indicators for assessing fish welfare in this module. According to the literature research on the European perch, all these parameters are necessary, and no additional parameters were added.

Intervals

Each individual parameter within the water quality module works with four intervals. Only the interval of the parameter "Body condition factor" was adapted to the needs of the European perch based on comprehensive literature research and empirical values. For the parameter body condition factor the interval limits had to be lowered as the perch has different body proportions compared to the pikeperch.

Score

To unify all the different parameters the intervals are scored. The best interval has a parameter score (PS) of 0 meaning the parameter has no negative impact on fish welfare. The second interval has a PS of -0.33 indicating a slight negative impact on fish welfare, followed by the third with a PS of -0.66. The fourth and last interval has a PS of -1 as it has a considerably negative impact on fish welfare. As there were no changes to the number of intervals, there are no adaptions to the scoring system needed.

Weights

The first version of the MyFishCheck model incorporated parameter weights that were defined with an extensive expert survey. During the literature research no reasoning was identified to rectify any changes in these weights.

2.2.6. Fish anatomy

The module fish anatomy contains parameters that describe internal physiological aspects of fish. Not the fish as an individual, but the average results of 3-10 fish should be entered into the MyFishCheck model. All these parameters in the module fish internal appearance contribute significantly to ensuring and improving fish welfare and are all relevant, practicable and reliable in relation to the collection and/or ensuring fish welfare. The module relates to the internal appearance of the fish body and thus contains all the important organs and their condition such as shape, colour, and alterations. In addition, all internal phenomena are taken into account, which indicate suboptimal husbandry and/or allow statements about fish welfare. This includes diseases and injuries which can become noticeable inside the fish.

It should be noted that parameters in this module can only be evaluated through a dissection of the fish. In concrete terms, this means that the fish must be killed and cut open professionally and in accordance with the prevailing legal situation. Most parameters are visible to the naked eye. Only the parameters "gill lamellae" and "gill pathogens" require a microscope with a magnification of 40 - 100 for evaluation.

Parameters

Within the module 10 parameters exist and were checked against a comprehensive literature review. Those parameters include the heart, kidney, spleen, liver, intestines, muscles, body cavity, reproductive organs, and gill lamellae represent the organs of the fish. Further, the parameter gill pathogens which rounds of the parameter gill lamellae considering possible pathogens on the fish's gills. According to the literature research on the European perch, all these parameters are necessary, and no additional parameters were added.

Intervals

Each parameter within the fish behaviour module works with four intervals. During the literature research no reasoning was identified to rectify any changes in these intervals.

Score

To unify all the different parameters the intervals are scored. The best interval has a parameter score (PS) of 0 meaning the parameter has no negative impact on fish welfare. The second interval has a PS of -0.33 indicating a slight negative impact on fish welfare, followed by the third with a PS of -0.66. The fourth and last interval has a PS of -1 as it has a considerably negative impact on fish welfare. As there were no changes to the number of intervals, there were no adaptions to the scoring system needed.

Weights

The first version of the MyFishCheck model incorporated parameter weights that were defined with an extensive expert survey. During the literature research no reasoning was identified to rectify any changes in these weights.

2.3. Implementation of the European perch into MyFishCheck app

The incorporation of a new fish species in the backend and frontend of the software application was done in close collaboration between the biologist (expert for the fish in question) and the programmer of the MyFishCheck team (expert for the app). While it is helpful if the biologist has basic knowledge in at least one coding language, it is not a prerequisite for a successful implementation as more assistance can be given by the programmer if needed. The necessary access to the code was via the GitHub account of the research group (github.zhaw.ch/AquacultureSystems/).

2.3.1. Adaptions to the system or location

Depending on the fish species adaptations, additions or omissions to the aquaculture system or the system location are necessary. If those are minor changes this can be done in the course of implementing the new fish species, which was the case for the European perch. As the comparatively similar pikeperch was already part of the app, there were no adaptions for the systems (recirculating and flowthrough) or the locations (indoors and outdoors) needed. If on the other hand, the alterations for a new species were considerable a separate development step should be considered, where first a new aquaculture system such as pond or sea cage is implemented and only afterwards the new fish species is developed.

2.3.2. Adaptations to the parameter intervals

The modularity of the software allows for new fish species to be added in a very straightforward way. After a two-letter acronym was defined for the species, "ep" in case of the European perch, the species was added to the code (Fig. 1). If the parameters were identical to the existing ones, "/ep" was added to the previous species rt/pp (rainbow trout and pikeperch) for locSysFish (Fig. 1, line 59). If, on the other hand, the intervals of the parameter were different, the line was duplicated and adapted for only the new species (Fig. 1, line 67f.). In this case the locations (in/out i.e., indoors and outdoors) and systems (ras/fts i.e., recirculating aquaculture system and flow-through system) the new species applies to must be repeated. The code was adapted in GitHub, and the changes directly committed afterwards.

```
55  class FarmManagement extends ModuleInfo {
56    FarmManagement({sysInfo})
57      : super(
58        [
59          ParamInfo(id: 'M0', name: 'personel training', locSysFis: 'in/out/ras/fts/rt/pp/ep', pw: 3, intervals: null),
60          ParamInfo(id: 'M1', name: 'daily check', locSysFis: 'in/out/ras/fts/rt/pp', pw: 3, intervals: null),
61          ParamInfo(id: 'M2', name: 'treatment journal', locSysFis: 'in/out/ras/fts/rt/pp', pw: 3, intervals: null),
62          ParamInfo(id: 'M3', name: 'target value sheet', locSysFis: 'in/out/ras/fts/rt/pp', pw: 4, intervals: null),
63          ParamInfo(id: 'M4', name: 'emergency plan', locSysFis: 'in/out/ras/fts/rt/pp', pw: 4, intervals: null),
64          ParamInfo(id: 'M5', name: 'hygiene concept', locSysFis: 'in/out/ras/fts/rt/pp', pw: 4, intervals: null),
65          ParamInfo(id: 'M6', name: 'mortality documentation', locSysFis: 'in/out/ras/fts/rt/pp', pw: 4, intervals: null),
66          ParamInfo(id: 'M7', name: 'biomass documentation', locSysFis: 'in/out/ras/fts/rt/pp', pw: 3.5, intervals: null),
67          ParamInfo(id: 'M8', name: 'stocking density', locSysFis: 'in/out/ras/fts/rt', pw: 3, intervals: [[0, 40], [40, 60], [60, 80]], unit: 'kg/m3'),
68          ParamInfo(id: 'M8', name: 'stocking density', locSysFis: 'in/out/ras/fts/pp', pw: 3, intervals: [[0, 30], [30, 50], [50, 80]], unit: 'kg/m3'),
69          ParamInfo(id: 'M9', name: 'sorting', locSysFis: 'in/out/ras/fts/rt/pp', pw: 3, intervals: null),
70          ParamInfo(id: 'M10', name: 'slaughter', locSysFis: 'in/out/ras/fts/rt/pp', pw: 5, intervals: null),
71          ParamInfo(id: 'M11', name: 'feeding interval and rate', locSysFis: 'in/out/ras/fts/rt/pp', pw: 3.5, intervals: null),
72          ParamInfo(id: 'M12', name: 'feed type', locSysFis: 'in/out/ras/fts/rt/pp', pw: 4, intervals: null),
73          ParamInfo(id: 'M13', name: 'disturbances', locSysFis: 'in/out/ras/fts/rt/pp', pw: 3.5, intervals: null),
74          ParamInfo(id: 'M14', name: 'ambiant light', locSysFis: 'in/ras/fts/rt/pp', pw: 3, intervals: null),
```

Figure 1: GitHub screen snippet from the modules.dart file, showing the farm management parameters during the implementation of the European perch.

2.3.3. Adaptations to the languages

To ensure maximal benefit, the new fish species was added to the software in all languages available within the app. In the case of European perch, no significant adaptations except for the species name were needed, as no parameters were added or considerably changed. If this was the case, it is important to ensure that the same adaptions are made in all languages (Fig. 2, left). Text was changed in the code in GitHub and directly committed. It was helpful to have a mobile phone version available to go through all the text, see how it was portrayed in the app and simultaneously look for existing spelling errors and grammar mistakes that can be corrected on the go (Fig. 2, right).

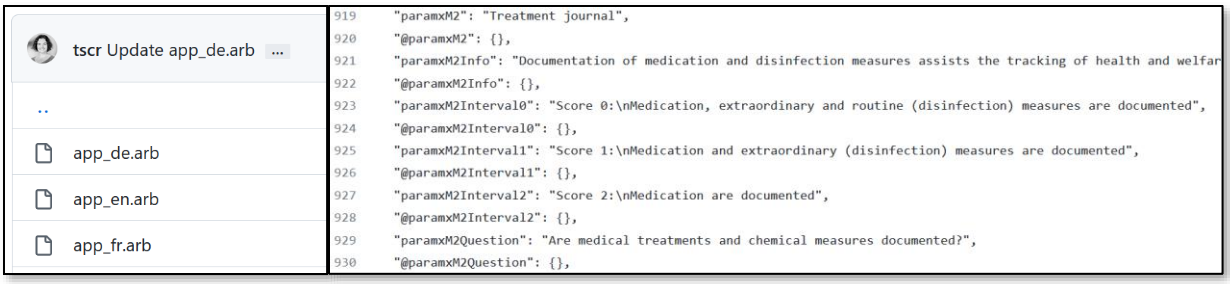

Figure 2: GitHub screen snippets from the different language files (left) and the English section for the parameter "treatment journal" in the farm management module (right).

2.3.4. Testing and development iterations

The testing phase is imperative to a successful new release and enough time must be allocated for this step. It was particularly important to have several iterations with the programmer where the new species was tested by different people on the app to spot small errors or larger issues. Only after the MyFishCheck team decided the implementation was completed, the new version of the software could go life on the homepage (www.MyAquacultureFarm.ch).

2.4. Including a new fish species into the MyFishCheck model

One key feature of the MyFishCheck model and its app is their modular build up. More fish species, languages or aquaculture system can be added for an increasingly broader applicability and continuously updated in the future with a growing database. This means that fish farmers, veterinarians, and biologists can benefit from a broader scope of MyFishCheck in the future and that they can adapt a standardised tool to their business and help shape it. The Standard Operating Procedure (SOP) written in this work serves to set a standard for the implementation process of other fish species.

2.4.1. Standardisation during the implementation

The SOP is intended to enable fish farmers, veterinarians, or biologists to contribute to MyFishCheck by adding new features in a standardised way. When developing an SOP for the implementation of new fish species in MyFishCheck, care was taken to ensure that it was designed and described as user-friendly and clearly as possible. In addition to the specific information on how to collect and prepare the data for implementation, background ideas are explained for a better understanding. The structure of the SOP was recorded using a flow chart with five consecutive steps which should be worked through sequentially. The MyFishCheck team guides any contributor through the process in case of any questions, uncertainties or suggestions.

2.4.2. Standardised procedure for implementation

The SOP is divided into five phases (Fig. 3), which are to be processed consecutively when a new fish species is implemented. During the first phase, the defining phase, the goals of the implementation are defined and recorded in writing. In the second phase, the data collecting phase, a comprehensive literature research is carried out on all parameters of the MyFishCheck model, and empirical values for the parameter intervals are included. The third phase, the data management phase, is used to enter all acquired data within the parameter table of MyFishCheck. The intervals and weights of the parameters (PW) can be adjusted in consultation with justification. All data on new fish species should be backed up with scientific literature and studies. However, after a full literature review and a first draft the parameter tables they need a review with aquaculture experts to ensure their applicability, internal coherence, and species or system specificity. It is for the team of experts to find the appropriate balance between all aspects. Once all the data has been defined, the parameter tables can be implemented by the programmer in order to start the fourth phase, the testing phase. Here the MyFishCheck app and model with the newly implemented fish species is used and tested, ideally on-site, at different aquaculture systems and by different people. If parameters, intervals or weights need further adjustment this is done in repeated development iterations together with the programmer. Errors, inconsistencies, and issues need to be solved and corrected before proceeding to the fifth and final phase. This last phase represents the go-live of the software. The detailed SOP can be found in Appendix F.

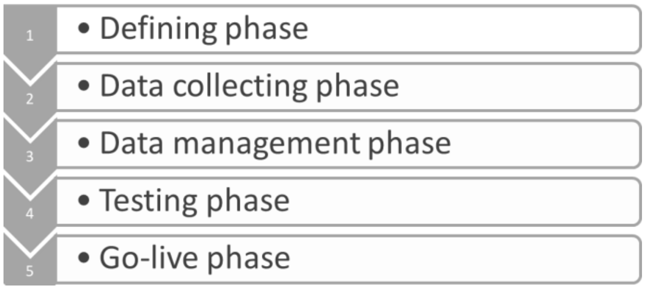

Figure 3: Overview of the SOP with the five consecutive steps.

3. Discussion

The three main goals of this work, the implementation of the European perch (*Perca fluviatilis*) into the MyFishCheck model, the inclusion of the new species in the mobile phone app, and the development of an SOP on the implementation of new fish species in the model, were successfully reached and posed task-specific challenges and opportunities along the way.

3.1. Including the European perch in the MyFishCheck model

As a first step and before the literature research, it is important to get a general overview of the topic. This includes obtaining information about the background of fish welfare in general and an initial insight into the model itself. Further, it is crucial to store references from the beginning using a reference management tool like Zotero.

3.1.1. Literature research for the European perch

Scientific literature on the European perch was not plentiful due to both not many papers existing in the first place and restricted access to some of them. Papers from universities such as Cambridge University or Wageningen University could not be considered due to missing licencing. Because of this problem with access to literature, it was quite helpful to be provided access to other Zotero online libraries with literature that had already been collected highlighting the importance of group effort and access to well established research groups. With the help of this existing literature, one could read up on the topic at the beginning of the thesis and gain a rough overview of relevant experts and their publications. Furthermore, it was a challenge to find suitable scientific publications that specifically addressed the European perch. This led to compromises necessary when implementing the data on the European perch in the MyFishCheck model. For example, information gaps for the redefinition of intervals were consulted with literature from similar fish like the pikeperch and discussed with experts in the field of fish and further adjusted with empirical experience.

In addition to the five freedoms concept and the concept with the definitions for ensuring fish welfare, further tools could be found with the literature search. The Fish Grimace Scale (FGS) was developed by a group of researchers led by Lynne Sneddon, a professor of animal welfare and ethics at the University of Liverpool (Sneddon, 2003a). The FGS assesses pain in fish by evaluating changes in facial expression, a technique that has been shown to be reliable in identifying pain in other species. The Fish Grimace Scale (FGS) was first described in a 2003 paper by Lynne Sneddon and colleagues, which was published in the journal "Animal Behaviour". The paper, titled "Evidence for pain in fish: the implications for the study of welfare", introduces the concept of the FGS and provides the first validation of the tool. Furthermore, there is the Fish Welfare Index (FWI). The Fish Welfare Index (FWI) was developed by a team of researchers at the University of Guelph in Canada, led by Dr. Helen Duncan (Duncan, 2007). The FWI is a composite index that consists of several sub-indices, including feeding, swimming, growth, and colour, and can be used to assess the general welfare state of fish in different environments. The development of the FWI was described in a 2007 paper by Helen Duncan and colleagues, published in the journal "Aquaculture Research". Both the Fish Welfare Index (FWI) and the Fish Grimace Scale (FGS) have been developed as tools to assess the welfare of farmed fish in general, rather than being specific to a particular species of fish.

3.1.2. Confirmation of parameters

All parameters that already existed in the MyFishCheck model were adopted when implementing the European perch. According to the literature research, all these parameters are necessary, and no additional parameters were added. This is partly because a relatively similar fish species, the pikeperch, was already included in the model providing a well-suited basis.

In the farm management, fish behaviour, and fish anatomy modules, neither the parameters nor the intervals were changed. The farm management module contains parameters that deal directly with the operators of a fish farm and their working standards and working procedures. The literature on which the module is based relates to all fish species. The module is therefore not structured in a species-specific manner and was therefore left unaltered. The fish behaviour module contains parameters that describe the dynamics and behavioural patterns of a fish shoal. The direct effects of potential stress situations on fish are comparable to each other, which is why no changes to parameters and intervals were judged to be relevant (Birnie-Gauvin et al., 2017). The module fish anatomy relates to the internal appearance of the fish body and thus contains important organs and their condition. The anatomy of the European perch (*Perca fluviatilis*) is in many respects similar to the previously implemented fish species the pikeperch (*Sander lucioperca),* since both fishes belong to the perch family (*Percidae*) (Adam et al., 2013; Eckmann & Schleuter-Hofmann, 2013). For this reason, the parameters and the intervals in this module were left unaltered.

No parameters have been adjusted in the water quality and fish morphology modules, but some intervals have. Compared to the other four modules, the module water quality is the most species-specific because fish have different needs for the water that surrounds them and its quality (Altinok et al., 2006; Svobodová et al., 1993). Therefore, some of the interval limits had to be adapted to the needs of the European perch. Within the fish morphology module, there was exactly one parameter whose interval had to be adjusted and that was the body condition factor parameter. This parameter results from a calculation with the body weight and the length of the fish and is therefore a species-specific parameter that had to be adjusted to the European perch (Ward & Mehta, 2010).

Nevertheless, there are different reasons to either add or drop parameters to the model and they have to be considered for every new species implementation. For example, a good reason to implement an additional parameter is that not all fish species have the same morphology (Su et al., 2019), e.g., a higher number of fins could justify an additional parameter. Furthermore, in the implementation of a saltwater fish, a parameter dealing with the salinity of the water or a comparison with the conductivity would be needed (Garcia-Gallego, 2007; Takahashi, 2016; Zhu et al., 2009). Additionally, depending on the system type of the fish farm, the omission of parameters can be decisive. The nitrogen parameters from the water quality module provide an example of this as the parameters ammonium, ammonia, nitrites, and nitrates are relevant for RAS but not for FTS.

3.1.3. Adapting intervals

The intervals, which were adjusted in the water quality and fish behaviour modules, were redefined based on the results of the literature research. The challenge of reference management arose. The literature that was relevant to the intervals was sorted in Excel. This form of management was of great help, especially in the intensive phase of literature research, since it is easy to lose track with a large number of references.

Since MyFishCheck is practicable it aims at practice in the form of empirical values and results from expert discussions (Tschirren et al., 2021), the redefined intervals were checked by experts before implementation. This approach is prone to conflicts between the results of the literature review and the practical approaches of fish farming. These conflicts can arise, for example, for economic reasons and can be addressed and resolved through compromises found within the literature results. While these compromises greatly aid the practicability of MyFishCheck, they need to be subject of frequent revisions and reviews to ensure that they do not jeopardize fish welfare.

3.1.4. Affirmation of scores and weights

All scores and weights that already existed in the MyFishCheck model were adopted when implementing the European perch. As there were no changes to the number of intervals, there were no adaptations to the scoring system needed. However, if the number of intervals within a module is increased or decreased, an adjustment of the scores is essential so that the model can calculate the module grades correctly (Tschirren et al., 2021).

The initial iteration of MyFishCheck utilized weights that were established through a comprehensive survey of experts in the field. All of these weighings are coordinated within the model. Since this work was not intended to deal in depth with the equation and the mathematical relationships of the weighing, the weights were left unchanged.

It is crucial to note that the model is intended to be adaptable, meaning that as new information becomes available parameters, intervals or weights may need to be adjusted accordingly (Tschirren et al., 2021). Further, this adaptability allows for corrections in case experiments or experience show that previously implemented values are not improving fish welfare. Such experiments of long-term experience through application would drastically benefit the model.

3.2. Implementing the perch into the MyFishCheck app

A programmer was needed for programming, which represented the actual implementation of the new data into the software. Even if certain programming knowledge was available, it was not sufficient for implementation on this scale. However, having a specialist in this area meant a gain in additional support and a more qualitative exchange of views throughout the implementation process. In this way, it was possible to discuss with the programmer in advance the formats in which the data on the European perch should be recorded in order to guarantee efficient implementation. Conversely, the programmer contributed to the topic by adapting his skills more precisely to the topic. Such interdisciplinary skills are becoming increasingly important as the rapid advancement of innovation in connection with digitization raises the question of efficient data collection and evaluation.

3.3. A SOP for future incorporation of fish species

The developed SOP is a tool to help with further implementations (Hall, 1986). The aim was to make the SOP as simple and logical as possible to guarantee reader- and user-friendliness to efficiently further develop MyFishCheck. This was implemented using an SOP in the form of a consecutive step-by-step guide. Written in short sentences to clearly present the information needed for the reader. For a better overview, the SOP was divided into five phases of the process, each of which was shown graphically on the respective page (Rau et al., 2019). The official templates for collecting the data of the fish species to be implemented were attached after the SOP. These represent a uniform template for all users and thus make a significant contribution to a standardised implementation process. One would have to work with these templates and nothing should be changed without consulting the MyFishCheck team, because this affects the entire calculation of the module grades in the background (Tschirren et al., 2021).

Within the first phase of the SOP, it is required to read the original MyFishCheck paper and this thesis. This process is essential to understand the MyFishCheck model with its function and goals and to get a simplified entry into the implementation process.

3.4. Planned steps and future ideas

The implementation of the fish species sea bream and sea bass as well as another system type of sea cages is planned for 2023. Additionally, Spanish will be implemented as another language (Tschirren et al., 2021). Further a comprehensive long-term study is needed to determine the applicability and effectiveness of the app in enhancing fish welfare. A general goal in the future of MyFishCheck is that it always adapts based on new information. These changes are achieved with the exchange of parameters and interval limits. In addition, adjustments to the MyFishCheck model can open up in other areas in the future. It is conceivable that the different life stages of the fish will be taken into account in the future and that adjustments will be made to the system types and areas of application of the model.

In further steps developing the SOP, future user feedback could be included. In addition, it would be conceivable that if the demand arises, a more interactive digital form of the SOP will be developed. Furthermore, it might be beneficial to use more images of each step, i.e., of the templates to use, to better guide the user (Rau et al., 2019).

3.5. Conclusions

An efficient implementation of a new fish species in MyFishCheck largely depends on how well you manage the collected references. It is imperative that the literature is stored in a dedicated tool such as Zotero. Furthermore, it is highly recommended to arrange the individual papers according to topic. In this way, the important data is always efficiently traceable and can be better linked to each other. In the future it will also be important to adapt the module to new innovations. New technologies could i.e., change the composition of the parameters.

Digitalization can be a powerful tool for improving fish welfare by allowing for the monitoring and tracking of fish health through the use of digital tools in combination with sensors and cameras, creating predictive models of fish behaviour with advanced algorithms and machine learning (Wang et al., 2021). Even if MyFishCheck has still room for improvement, it can already now offer a great help to raise fish welfare and improve fish health. Together with other welfare tools which are intended to serve the assessing of fish welfare, an important basis for fish farms is created in order to grant fish welfare in aquaculture in the future.

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5. Table of figures

6. Table directory

7. Appendix A: Farm management parameters

Personnel training: The welfare of fish depends on various factors and parameters. Good education and training of the fish farmers can help ensure that potential problems within the fish farm are resolved quickly. A quick and professional handling of a problem secures fish welfare. The lowest education which at least one person has to have in a fish farm in Switzerland is the FBA Aquakultur. In Switzerland this education is a legal minimum to operate a fish farm (*FAWC Report on the Welfare of Farmed Fish*, 1996; Segner et al., 2019). For this reason, it is important to keep the parameter "Personnel training" within this module. The weight of this parameter (PW) was set at 3 out of 5.

Daily check: Daily checks of the farm's systems can help to ensure that any problems are identified early. With an early detection and identification of a potentially upcoming problem, one can prevent them which affects fish welfare (Bregnballe, 2015; *FAWC Report on the Welfare of Farmed Fish*, 1996). For this reason, it is important to keep the "Daily check" parameter within this module. The weight of this parameter (PW) was set at 5 out of 5.

Disturbances: External disturbances, such as noise or vibrations, can influence the behaviour of the fish and should therefore be avoided. To ensure good welfare, a reduction of external disturbances to only the unavoidable level is necessary (Jentoft et al., 2006). For this reason, it is important to leave the "Disturbances" parameter within this module. The weight of this parameter (PW) was set at 3.5 out of 5.

Predator protection: Protecting fish from predators is important to ensure fish welfare. Predators like birds or mammals can attack and injure the fishes (*FAWC Report on the Welfare of Farmed Fish*, 1996). For this reason, it is important to keep the "Predator protection" parameter within this module. The weight of this parameter (PW) was set at 4 out of 5.

Plant cleanliness: The cleanliness of the fish farm is important to maintain the health of the fish. A Proper cleaning and storage process as well as a hygiene protocol can help improve fish welfare (Bregnballe, 2015; Klontz, 1991; North et al., 2008). For this reason, it is important to keep the "Plant cleanliness" parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Treatment journal: A journal with documentation on medication and disinfection measures helps to track the health process of the fish and is mandatory in Switzerland (North et al., 2008). For this reason, it is important to keep the "Treatment journal" parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Target value sheet: A target agreement document provides information about the goals of a fish farm and can help to achieve them. In combination with action plans which are corresponding to different outcomes of a set target value can secure fish welfare (North et al., 2008). For this reason, it is important to leave the "Target value sheet" parameter inside this module. The weight of this parameter (PW) was set at 4 out of 5.

Emergency plan: An emergency concept with an emergency plan gives instructions on how to act in an emergency to ensure welfare of the fish. In order to be able to act as appropriate as possible in an emergency situation, an emergency plan must be adapted to the individual systems of a fish farm (Bregnballe, 2015; North et al., 2008; Segner et al., 2019).For this reason, it is important to keep the "Emergency plan" parameter within this module. The weight of this parameter (PW) was set at 4 out of 5.

Hygiene concept: A hygiene concept describes how hygiene can be ensured in the fish farm. Good hygiene concepts can have a positive and direct impact on fish welfare through less contamination of the system water (Bregnballe, 2015; Meyer, 1991; Noble et al., 2020). For this reason, it is important to keep the "Hygiene concept" parameter within this module. The weight of this parameter (PW) was set at 4 out of 5.

Mortality documentation: A documentary about fish deaths provides information about possible problems in the fish farm. In order to detect such possible problems to improve fish welfare, it is important to document the fish mortalities and the chronological data of the system as precisely as possible (Kleingeld et al., 2016). For this reason, it is important to keep the "Mortality documentation" parameter within this module. The weight of this parameter (PW) was set at 4 out of 5.

Biomass documentation: A document for recording the biomass in combination with the FCR (feed conversion ratio) provides information about the growth rate of the fish and can be used as an indicator for fish welfare. Together with the stocking density, the documentation of the biomass improves procedures like the feeding process or for fixing the optimal time for sorting or slaughtering (Kleingeld et al., 2016; Klontz, 1991; Woynarovich et al., 2011). For this reason, it is important to keep the "Biomass documentation" parameter within this module. The weight of this parameter (PW) was set at 3.5 out of 5.

Sorting: Sorting the fish by size in a fish tank can help keep the fish comfortable. Although the procedure of sorting of a shoal can be stressful for the fishes, a homogeneously sized group of fish improves fish welfare in the long-term. Setting the right sorting intervals is necessary to avoid unwanted stress for the fishes (Baekelandt et al., 2018). For this reason, it is important to keep the "Sorting" parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Slaughter: The definition and laws of a humane slaughtering process is declared and prescribed in Switzerland by the federal government. A humane slaughter process is very important in terms of improving fish welfare (Ellis et al., 2012). For this reason, it is important to keep the "Slaughter" parameter within this module. The weight of this parameter (PW) was set at 5 out of 5.

Stocking density: The current stocking density of the fish can influence the behaviour of the fish and should therefore be taken into account. If a stocking density is too low, it can have negative impacts on fish welfare as well as a too high stocking density. A not properly managed stocking density can lead to territoriality and or aggression of fish. Furthermore, a not properly managed stoking density can affect other parameters such as the water quality and the behaviour of fish in a group (Dalsgaard et al., 2013). For this reason, it is important to keep the "Stocking density" parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Feeding interval and rate: The feeding intervals affect the growth rate and health of the fish. The appropriate feed type depends on the fish species. A specific feeding interval and specific amount of feed per feeding improves fish welfare. The feeding intervals and rate affect growth, health, and the behaviour of a fish or shoal (López-Olmeda et al., 2012). For this reason, it is important to keep the "Feeding interval and rate" parameter within this module. The weight of this parameter (PW) was set at 3.5 out of 5.

Feed type: A balanced diet tailored to the specific needs of the fish and careful control of the amount of feed are important to optimize the welfare of the fish. The feeding process and the size of the feed is decisive for fish welfare (Antony Jesu Prabhu et al., 2015; Baekelandt et al., 2018; Geay & Kestemont, 2015). For this reason, it is important to keep the "Feed type" parameter within this module. The weight of this parameter (PW) was set at 4 out of 5.

Ambient light: The exposure of the fish farm and its ambience can affect the welfare of the fish. The ambient light can be an external factor which influences biological processes of a fish species and therefore has to be adjusted properly to improve fish welfare (Karakatsouli et al., 2007; Mizusawa et al., 2007). For this reason, it is important to keep the "Ambient light" parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Tank light: Fish tank lighting can affect fish behaviour. Besides the influence on biological processes, light conditions within the fish tank can have an impact on the fishes social and feeding behaviour which influences fish welfare (Feiner & Höök, 2015; Geay & Kestemont, 2015; Luchiari et al., 2006). For this reason, it is important to leave the "Tank light" parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

	Literature	Remarks	Parameter question	Location System Species	Parameter	Parameter intervals	PS	SW	PW	SWE PWE
Farm management	Ashley 2007; FAWC 1996 ; North et al. 2008; Segner et al. 2019	*Ensuring the welfare of farmed fish requires good education, training, and experience on the part of fish farmers. In Switzerland, the law mandates that at least one person working on a fish farm must have completed the 'FBA Aquakultur' course.*	What is the highest training of the personnel in charge?	In / Out RAS / FTS EP	Personnel training	0: Apprenticeship/master degree with work experience	0	1	3	
						1: Apprenticeship/master degree in Aquaculture or "FBA Aquakultur" with work experience	-0.5	3		
						2: "FBA Aquakultur"	-1	5		
	FAWC 1996 ; Timmons et al. 2010; Bregnballe 2015	*Performing regular checks on the fish farming system can help identify and prevent issues that may affect the welfare of farmed fish. The frequency of these checks will vary depending on the specific components of the system being monitored, the type of fish farming system being used, and the life stage of the fish being raised.*	How are the farm's systems checked?	In / Out RAS / FTS EP	Daily check	0: Daily check with appropriate controls	0	1	5	
						1: Daily check	-0.5	3		
						2: System is checked insufficiently	-1	5		
	Jentoft et al. 2005 ; North et al. 2008; Noble et al. 2020	*Minimizing unnecessary disturbances in fish farming can help promote good fish welfare by limiting stress on the fish.*	Are the fish exposed to external disturbances?	In / Out RAS / FTS EP	Disturbances	0: No external disturbances	0	1	3.5	
						1: Little or slight disturbances	-0.5	3		
						2: Frequent and / or severe disturbances	-1	5		
	Huntingford et. al., 2006; FAWC 1996; North et al. 2008; Noble et al. 2020	*Predation from birds or mammals can impact welfare through attacks and injuries.*	Are the fish protected from predators?	Out RAS / FTS EP	Predator protection	0: Completely protected from predators	0	1	4	
						1: Partially protected from predators	-0.5	3		
						2: Not protected	-1	5		
	Klontz 1991; North et al. 2008; Bregnballe 2015	*Properly storing, cleaning, and handling all materials used in the fish farming system helps ensure the system functions properly and follows good hygiene protocols, which in turn promotes the welfare of farmed fish.*	Is the farm and the used material kept clean?	In / Out RAS / FTS EP	Plant cleanliness	0: The farm is clean and tidy, working materials are clean and disinfected	0	1	3	
						1: The farm is clean, working materials are clean	-0.5	3		
						2: The farm is chaotic and dirty, working materials dirty	-1	5		
	Toni et al., 2019; North et al. 2008; BLV 2016	*Documenting the use of medication and disinfection measures helps to track the health and welfare of farmed fish and the effectiveness of these measures. In Switzerland, it is required by law to document the use of any medication in fish farming.*	Are chemical measures documented?	In / Out RAS / FTS EP	Treatment journal	0: Medication, extraordinary and routine (disinfection) measures are documented	0	1	3	
						1: Medication and extraordinary (disinfection) measures are documented	-0.5	3		
						2: Medications are documented	-1	5		
		Having written, easily accessible information about the target values for the fish farming system and plans of action in case those values are not met can help ensure the health and welfare of farmed fish.	Are target values and action plans available?	In / Out RAS / FTS EP	Target value sheet	0: Target value document and action plan are accessible	0	1	4	
						1: Target value document and an action plan are known, but not documented	-0.5	3		0 1.7
						2: There are no target values or specific action plan applied	-1	5		
	North et al. 2008; Bregnballe 2015; Segner et al. 2019	*Having specific, easily accessible emergency plans in place can help promote the health and welfare of farmed fish.*	Is an emergency plan available?	In / Out RAS / FTS EP	Emergency plan	0: An appropriate emergency plan is available and accessible	0	1	4	
						1: An appropriate emergency plan is known, but not documented	-0.5	3		
						2: No emergency plan is available, or it is not appropriate	-1	5		
	Reinertsen & Haaland 1995; Meyer 1991; Bregnballe 2015; Noble et al. 2020	*Having written, easily accessible hygiene protocols that are specific to the system in place can help ensure the health and welfare of farmed fish.*	Is a hygiene concept available?	In / Out RAS / FTS EP	Hygiene concept	0: An appropriate hygiene concept is available and accessible	0	1	4	
						1: An appropriate hygiene concept is applied, but not documented	-0.5	3		
						2: No emergency hygiene is available, or it is not appropriate	-1	5		
	Schweizer TSchV 2008; Ellis et al. 2012; Kleingeld et al. 2016	*Documenting instances of mortality can help track the health and welfare of farmed fish and the effectiveness of measures taken to address any problems. In Switzerland, it is required by law to document any mortality in fish farming.*	Are mortalities documented?	In / Out RAS / FTS EP	Mortality documentation	0: All mortalities and their cause are documented and deducted from biomass	0	1	4	
						1: All mortalities are documented and deducted from the biomass	-0.5	3		
						2: All mortalities are documented	-1	5		
	Klontz 1991; Woynarovich et al. 2011; Kleingeld et al. 2016	*Documenting biomass and stocking density can help ensure appropriate feeding, proper system maintenance, and timely husbandry procedures, all of which contribute to the welfare of farmed fish. The feed conversion ratio (FCR) is a measure of fish health and farm management.*	Are biomass, stocking density and FCR documented?	In / Out RAS / FTS EP	Biomass documentation	0: Biomass/stocking density are documented and recalculated (including the FCR) and sporadically verified with intermediate weighings	0	1	3.5	
						1: The biomass and stocking density are documented and sporadically verified with intermediate weighings	-0.5	3		
						2: The biomass is documented	-1	5		
	Hufschmied et. al., 2011; Schreck 1981; Zienert & Heidrich 2005; Zakęś et al. 2004; Baekelandt et al. 2018	*Sorting the fish in a group by size can help maintain a homogeneously sized population, but the process can also be stressful for the fish. Carefully selecting the appropriate sorting procedure and interval can help promote the long-term health and welfare of farmed fish.*	Is the sorting interval appropriate?	In / Out RAS / FTS EP	Sorting	0: The group is homogeneous	0	1	3	
						1: The group is slightly heterogeneous, unproblematic	-0.5	3		
						2: The group is very heterogeneous, problematic	-1	5		
	Robb 2008; Ellis et al. 2012; Lines & Spence 2012	*Ensuring humane slaughter of farmed fish involves minimizing the time spent crowded together, effectively stunning the fish, and quickly killing them. In Switzerland, fish must not exhibit any signs of consciousness between stunning and death.*	Is the slaughter process humane?	In / Out RAS / FTS EP	Slaughter	0: Crowding: Short / stunning method: effective / killing: fast / no fish shows reflexes	0	1	5	
						1: Crowding: Short / stunning method: effective / killing: delayed / no fish shows reflexes	-0.5	3		
						2: Crowding: long / stunning method: effective / killing: delayed / no fish shows reflexes	-1	5		

	Literature	Remarks	Parameter question	Location System Species	Parameter	Parameter intervals	PS	SW	PW	SWE PWE
Farm management	Branson 2008; Zienert & Heidrich 2005; Steenfeldt et al. 2010; Dalsgaard et al. 2013	The stocking density of farmed fish can affect other factors that impact welfare, such as water quality and group behaviour. In some systems, low densities may lead to increased aggression and territoriality within the group.	What is the current stocking density?	In / Out RAS / FTS EP	Stocking density	0: 0–30 kg/m³	0	1	3	0 1.7
						1: 30–50 kg/m³	-0.5	3		
						2: 50–80 kg/m³	-1	5		
	McCarthy et al. 1992; Moutou et al. 1998; Wang et al. 2009; López-Olmeda et al. 2012	The rate at which fish are fed (kg feed / kg biomass) and the interval between feedings (amount of feed per feeding and number of feedings per day) can impact growth, health, and social behaviour.	The current feeding interval and rate secures how many points?	In / Out RAS / FTS EP	Feeding interval and rate[1]	0: 5–6 points	0	1	3.5	
						1: 3–4 points	-0.5	3		
						2: 0–2 points	-1	5		
	Geay & Kestemont 2015; Antony Jesu Prabhu et al. 2015; Baekelandt et al. 2018	The type and size of feed used should be appropriate for the species and life stage of the fish being raised.	Is the feed type and size appropriate?	In / Out RAS / FTS EP	Feed type	0: Feed type and pellet size are adapted to the fish	0	1	4	
						1: Pellets are too small / big for the animals	-0.5	3		
						2: Type and size does not match the fish	-1	5		
	Noble et al. 2005; Karakatsouli et al. 2007; Mizusawa et al. 2007	Ambient light can have significant effects on biological processes and therefore the health and welfare of farmed fish. The appropriate light conditions will vary depending on the species and life stage of the fish.	Is the ambient light appropriate?	In RAS / FTS EP	Ambient light[2]	0: Light intensity and phases are adjusted	0	1	3	
						1: Light intensity or light phases are adjusted	-0.5	3		
						2: Neither light intensity nor light phases are adjusted	-1	5		
	Christensen et. al., 2020; Molnar et. al., 2022; Vanina et. al., 2019; Stejksal et. al., 2009; Luchiari et al. 2006; Geay & Kestemont 2015	The light conditions in tanks can affect the social and feeding behaviour of farmed fish. The appropriate light conditions will vary depending on the species and life stage of the fish, as well as the type of fish farming system being used.	Is the light in the husbandry tanks appropriate?	In RAS / FTS EP	Tank light[3]	0: Light intensity and light distribution adapted	0	1	3	
						1: Light intensity or light distribution adapted	-0.5	3		
						2: Neither intensity nor light distribution adapted	-1	5		
				Out RAS / FTS EP	Tank light[4]	0: Light intensity and light distribution adapted	0	1		
						1: Light intensity or light distribution adapted	-0.5	3		
						2: Neither intensity nor light distribution adapted	-1	5		

1 ▪ no feed leftovers ▪ good spatial distribution of the feed in the tank ▪ enthusiastic feeding behavior (neither apathetic nor aggressive) ▪ all fish receive enough food (also subdominant fish) ▪ neither overfed nor emaciated fish ▪ is adjusted weekly

2
- Light intensity: the (room) lighting allows safe working of the personnel and a visual inspection of the fish
- Light intensity: the room lighting is not too strong, the fish behaves calmly
- Light phases: any transitions from light/dark phases are long/gentle, fish always remain calm

3
- Light intensity: fish have a weak light intensity (either by shading or sufficient water depth or weak ambient light)
- Light intensity: Light intensity in the tank allows the fish a safe feed intake (they see the feed)
- Light distribution: no or weak light/dark transitions in the pool, group uses the entire water volume

4
- Light intensity: fish are protected from UV radiation (either by shading or sufficient water depth)
- Light distribution: no/weak light/dark transitions in the pool, swarm uses the entire water volume

8. Appendix B: Water quality parameters

Temperature: Water temperature is an important factor as it affects the fish's metabolic functions. Temperatures that are too high or too low can lead to stress and disease in the fish. It is therefore important that the water temperature is kept within the appropriate range for the individual fish species to improve fish welfare (Christensen et al., 2020; Ekstro & Pichaud, 2017; Ekström et al., 2016; Gebauer et al., 2021; Jensen et al., 2017; Orban et al., 2007; Policar et al., 2015; Sandström et al., 1995; Wolter, 2018; Yancheva et al., 2014). For this reason, it is important to keep the "Water temperature" parameter within this module. The weight of this parameter (PW) was set at 4 out of 5.

Oxygen and Oxygen saturation: Fish need oxygen to breathe and survive. The oxygen content of the water should therefore be kept within the range suitable for the fish species. The oxygen content of the water can be increased by the natural photosynthesis of plants and algae and by mechanical air pumps. The oxygen saturation of the water indicates how much oxygen there is compared to the amount of water. Further, oxygen saturation should be maintained within the optimal range to ensure fish welfare (Christensen et al., 2020; Ekström et al., 2016; Lushchak & Bagnyukova, 2006; Policar et al., 2015; Stejskal et al., 2009). For this reason, it is important to keep the "Oxygen" and "Oxygen saturation" parameters within this module. The weight of these parameters (PW) was set at 5 out of 5.

Ammonium: Too high ammonium concentrations can lead to stress and diseases in the fish. It is therefore important that the ammonium level in the water is kept within the optimum range to ensure fish welfare (Gebauer et al., 2021; Pohling, 2015; Stejskal et al., 2009). For this reason, it is important to keep the "Ammonium" parameter within this module. The weight of this parameter (PW) was set at 4 out of 5.

Ammonia: Ammonia is a toxic substance produced by fish and other aquatic animals. Ammonia concentrations that are too high can lead to stress and disease in the fish. It is therefore important that the ammonia-nitrogen level in the water is kept within the optimum range to ensure fish welfare (Christensen et al., 2020; Pohling, 2015; Policar et al., 2015). For this reason, it is important to keep the "Ammonia" parameter within this module. The weight of this parameter (PW) was set at 5 out of 5.

Nitrite: Nitrite is a toxic substance produced during nitrification, a biological process that takes place on the fish farm. Too high nitrite concentrations can lead to stress and diseases in the fish. It is therefore important that the nitrite-nitrogen level in the water is maintained within the optimum range to ensure fish welfare (Gebauer et al., 2021; Pohling, 2015; Policar et al., 2015; Toomey et al., 2019). For this reason, it is important to keep the "Nitrite" parameter within this module. The weight of this parameter (PW) was set at 5 out of 5.

Nitrate: Nitrate is a substance produced during nitrification and is normally found in water in low concentrations. However, too high nitrate concentrations can lead to stress and diseases in the fish. It is therefore important that the nitrate-nitrogen level in the water is maintained within the optimum range to ensure fish welfare (Zienert & Heidrich, 2005). For this reason, it is important to keep the "Nitrate" parameter within this module. The weight of this parameter (PW) was set at 2.5 out of 5.

Carbonate hardness: The carbon hardness of the water indicates how much calcium carbonate is contained in the water. The carbon hardness of the water affects the stability of the water and the biological processes that take place in the fish farm. It is important that the carbon hardness of the water is maintained within the optimum range to ensure fish welfare (Altinok et al., 2006; Steinberg, Zimmermann, Meyer, et al., 2018; Wedemeyer, 1996). For this reason, it is important to keep the "Carbonate hardness" parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Total suspended solids: Total Suspended Solids (TSS) indicates how much dirt and particles are suspended in the water. TSS levels that are too high can lead to stress and disease in the fish. It is therefore important that TSS levels in the water are maintained within the optimum range to ensure fish welfare (Steinberg, Zimmermann, Meyer, et al., 2018; Wedemeyer, 1996). For this reason, it is important to keep the "Total suspended solids" parameter within this module. The weight of this parameter (PW) was set at 2 out of 5.

pH: The pH indicates how acidic or basic the water is. Fish generally have a certain pH tolerance and can only remain healthy within a certain pH range. It is therefore important that the pH of the water is maintained within the appropriate range for the fish species to ensure fish welfare (Christensen et al., 2020; Gebauer et al., 2021; Rask, 1984; Stejskal et al., 2009; Yancheva et al., 2014). For this reason, it is important to keep the "pH" parameter within this module. The weight of this parameter (PW) was set at 4 out of 5.

Conductivity: The conductivity of water indicates how well the water conducts electricity. It is usually determined by the level of dissolved salts and minerals in the water. The electrical conductivity of the water affects the metabolic functions of the fish and should therefore be kept within the optimum range to ensure fish welfare (Copp, 2003; Yancheva et al., 2014). For this reason, it is important to keep the "Conductivity" parameter within this module. The weight of this parameter (PW) was set at 2 out of 5.

Carbon dioxide: Dissolved carbon value in water: The dissolved carbon value in water indicates how much carbon dioxide (CO_2) is present in the water. CO_2 levels that are too high can lead to stress and disease in the fish. It is therefore important that the level of dissolved carbon in the water is maintained within the optimum range to ensure fish welfare (Pohling, 2015; Steinberg et al., 2017; Wedemeyer, 1996). For this reason, it is important to keep the "Carbon dioxide" parameter within this module. The weight of this parameter (PW) was set at 3.5 out of 5.

Total gas pressure: Total Pressure Gas Pressure tells how much gas pressure there is in the water. Gas pressure in the water can affect fish and should therefore be kept within the optimal range to ensure fish welfare (Bohl, 1997; Wedemeyer, 1996; Weitkamp & Katz, 1980). For this reason, it is important to keep the "Total gas pressure" parameter within this module. The weight of this parameter (PW) was set at 4 out of 5.

Water velocity: Water velocity describes how fast the water is flowing through the fish tank in a fish farm. Fish have different water velocity requirements, and it is important that the water velocity is maintained within the appropriate range for the fish species to ensure fish welfare (Jobling et al., 1993; Larsen et al., 2012). For this reason, it is important to keep the "Water velocity" parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

	Literature	Remarks	Parameter question	Location System Species	Parameter	Parameter intervals	PS	SW	PW	SWE PWE
Water quality	Ekström 2016; Sandström 1995; Ekstro & Pichaud 2017; Christensen et. al., 2020; Jensen et. al., 2017; Policar et. al., 2015; Orban et. al., 2007; Gebauer et. al., 2021; Wolter 2018; Yancheva et. al., 2014	Water temperature can impact biological processes and is an important aspect of water quality for farmed fish. The preferred and tolerated temperatures will vary depending on the species and life stage of the fish, and the intervals should be adjusted accordingly.	Temperature of the system water in [°C]	In / Out RAS / FTS EP	Temperature	Optimum: [20 -24]	0	1	4	1.7 1.7
						Within target range: [10 - 20) ∪ (24 - 27]	-0.33	2.33		
						Within the tolerance range: [7 - 10) ∪ (27 - 29]	-0.66	3.66		
						Outside the tolerance range: [0 - 7) ∪ (29 - 40]	-1	5		
	Grapci et. al., 2019, Schäfer et. al., 2021; Stejksal et. al., 2009; Yancheva et. al., 2014	Oxygen is essential for biological processes and is a key aspect of water quality for farmed fish. Although the preferred levels of oxygen are similar for most species, the tolerance ranges will vary depending on the species and life stage of the fish, and the intervals should be adjusted accordingly.	Dissolved oxygen (O_2) in the system water in [mg/l]	In / Out RAS / FTS EP	Oxygen	Optimum: [7 - 9]	0	1	5	
						Within target range: [6.5 - 7) ∪ (9 - 13]	-0.33	2.33		
						Within the tolerance range: [6 – 6.5) ∪ (13 - 15]	-0.66	3.66		
						Outside the tolerance range: [2 - 6) ∪ (15 - 30]	-1	5		
	Ekström 2016; Christensen et. al., 2020; Policar et. al., 2015; Lushchak et. al., 2006; Stejksal et. al., 2009		Dissolved oxygen (O_2) in the system water in [% saturation]	In / Out RAS / FTS EP	Oxygen saturation	Optimum: [80- 120]	0	1	5	
						Within target range: [60 - 80) ∪ (120 - 140]	-0.33	2.33		
						Within tolerance range: [50 - 60) ∪ (140 - 150]	-0.66	3.66		
						Outside the tolerance range: [20 - 50) ∪ (150 - 300]	-1	5		
	Gebauer et. al., 2021; Stejksal et. al., 2009; Pohling 2015	Ammonium is toxic to fish and is an important water quality parameter in recirculating aquaculture systems (RAS). While there is limited data available on the tolerances of European perch, it is assumed that the tolerance for ammonium in pikeperch and European perch is similar, as the toxicity of ammonia is similar in both species. As a result, the same intervals for ammonium are used for both species.	Total ammonia nitrogen (TAN, NH_4-N + NH_3-N) of the system water in [mg/l]	In / Out RAS EP	Ammonium	Optimum: [0 - 0.5]	0	1	4	
						Within target range: (0.5 – 1.5]	-0.33	2.33		
						Within tolerance range: (1.5 - 5]	-0.66	3.66		
						Outside the tolerance range: (5 - 20]	-1	5		
	Christensen et. al., 2020; ; Policar et. al., 2015; Pohling 2015	Ammonia is highly toxic to fish and is an important water quality parameter in recirculating aquaculture systems (RAS). The levels of ammonia in the water can be calculated based on the total ammonia nitrogen (TAN) and pH values.	Ammonia (NH_3-N) of the system water in [mg/l]	In / Out RAS EP	Ammonia	Optimum: [0 - 0.01]	0	1	5	
						Within target range: (0.01 - 0.02]	-0.33	2.33		
						Within tolerance range: (0.02 - 0.1]	-0.66	3.66		
						Outside the tolerance range: (0.1 - 2]	-1	5		
	Policar et. al., 2015; Gebauer et. al., 2021; Vanina et. al., 2019; Pohling 2015	Nitrite is highly fish toxic and a relevant water quality parameter in RAS. In Switzerland, the upper limit for nitrite in the system water is 1.5 mg/l.	Nitrite (NO_2-N) of the system water in [mg/l]	In / Out RAS EP	Nitrite	Optimum: [0 - 0.05]	0	1	5	
						Within target range: (0.05 - 0.1]	-0.33	2.33		
						Within tolerance range: (0.1 - 0.5]	-0.66	3.66		
						Outside the tolerance range: (0.5 - 5]	-1	5		
	Rümmler et al., 2018; Schreckenbach, 2002, Zienert et al., 2005; Heidrich et al., 2006	Nitrate is fish toxic in high concentrations and a relevant water quality parameter in RAS. Before nitrate concentrations poses an acute risk for the fish, they hinder the proper functioning of the biofilter, what leads to an increase of nitrite and TAN.	Nitrate (NO_3-N) of the system water in [mg/l]	In / Out RAS EP	Nitrate	Optimum: [0 - 80]	0	1	2.5	
						Within target range: (80 - 100]	-0.33	2.33		
						Within tolerance range: (100 - 200]	-0.66	3.66		
						Outside tolerance range: (200 - 500]	-1	5		

	Literature	Remarks	Parameter question	Location System Species	Parameter	Parameter intervals	PS	SW	PW	SWE PWE
Water quality	Wedemeyer 1996; Altinok et al. 2006; Boyd et al. 2016	*The carbonate hardness of the water can impact the stability of the water quality and the biological processes of the fish. Degrees of hardness (°fH and °dH) can be converted into milligrams per liter (mg/L) of calcium carbonate.*	Carbonate hardness of the system water in $CaCO_3$ [mg/l]	In / Out RAS / FTS EP	Carbonate hardness	Optimum: [40 - 150]	0	1	3	1.7 1.7
						Within target range: [30 - 40) ∪ (150 - 250]	-0.33	2.33		
						Within tolerance range: [20 - 30) ∪ (250 - 400]	-0.66	3.66		
						Outside tolerance range: [0 - 20) ∪ (400 - 500]	-1	5		
	Wedemeyer 1996; Becke et al. 2018; Steinberg et al. 2018a	*High levels of total suspended solids (TSS) can indicate poor water quality and can affect the function and health of the gills in farmed fish.*	TSS of the system water in [mg/l]	In / Out RAS / FTS EP	Total suspended solids	Optimum: [0 - 25]	0	1	2	
						Within target range: (25 - 50]	-0.33	2.33		
						Within tolerance range: (50 - 200]	-0.66	3.66		
						Outside tolerance range: (200 - 500]	-1	5		
	Christensen et. al., 2020; Gebauer et. al., 2021; Rask et. al., 1984; Yancheva et. al., 2014; Stejksal et. al., 2009	*The pH of the water can impact the biological processes of the fish and the biofilter, and is an important aspect of water quality. In Switzerland, the legal range for pH in fish farming systems is 5.5 - 9.*	pH of the system water	In / Out RAS / FTS EP	pH	Optimum: [7 - 7.8]	0	1	4	
						Within target range: [6.5 - 7) ∪ (7.8 - 8]	-0.33	2.33		
						Within the tolerance range: [6 - 6.5) ∪ (8 - 8.5]	-0.66	3.66		
						Outside the tolerance range: [4 - 6) ∪ (8.5 - 10]	-1	5		
	Yancheva et. al., 2014; Copp 2003; Scott et al. 2008; Xiong et al. 2019	*The preferred and tolerated levels of salinity vary greatly among fish species, so it is important to consider this parameter when assessing the suitability of a particular species for salt or brackish water. For freshwater species, salinity can be measured through conductivity. However, other ions such as nitrate can also affect conductivity and limit the upper levels that are acceptable for the welfare of the fish before the salinity itself becomes a welfare concern.*	Conductivity of the system water in [µS/cm]	In / Out RAS / FTS EP	Conductivity	Optimum: [500 - 1000]	0	1	2	
						Within target range: [300 - 500) ∪ (1000 - 5000]	-0.33	2.33		
						Within tolerance range: [200 - 300) ∪ (5000 - 15000]	-0.66	3.66		
						Outside tolerance range: [0 - 200) ∪ (15000 - 30000]	-1	5		
	Pohling et. al., 2015; Wedemeyer 1996; Good et al. 2010; Steinberg et al. 2017	*Elevated levels of dissolved carbon dioxide impair fish health and can occur in RAS as well as FTS.*	Dissolved carbon dioxide (CO_2) in the system water in [mg/l]	In / Out RAS / FTS EP	Carbon dioxide	Optimum: [0 - 5]	0	1	3.5	
						Within target range: (5 - 10]	-0.33	2.33		
						Within tolerance range: (10 - 25]	-0.66	3.66		
						Outside the tolerance range: (25 - 100]	-1	5		
	Weitkamp et al. 1980; Wedemeyer 1996; Bohl 1997	*Elevated levels of total gar pressure in the system water impair fish health and can occur in RAS as well as FTS.*	TGP in the system water in [% saturation]	In / Out RAS / FTS EP	Total gas pressure	Optimum: < / = 100	0	1	4	
						Within target range: (100 - 103]	-0.33	2.33		
						Within tolerance range: (103 - 105]	-0.66	3.66		
						Outside tolerance range: (105 - 120]	-1	5		
	Jobling et al. 1993; Lauff & Wood 1996; Larsen et al. 2012	*The velocity of the water can impact both the welfare of the fish (e.g. through physiological exercise and group behaviour) and the functioning of the system (e.g. tank self-cleaning and biofilter efficiency). The optimal and tolerated levels of water velocity will vary depending on the species and life stage of the fish and the specific system being used, and should be adjusted accordingly.*	Water velocity in the fish tank in [body lengths/sec]	In / Out RAS / FTS EP	Water velocity	Optimum: [0.5 - 1]	0	1	3	
						Within target range: [0.3 - 0.5) ∪ (1 - 2]	-0.33	2.33		
						Within tolerance range: [0.2 - 0.3) ∪ (2 - 3]	-0.66	3.66		
						Outside the tolerance range: [0 - 0.2) ∪ (3 - 5]	-1	5		

9. Appendix C: Fish behaviour parameters

Aggression: The aggressive behaviour of fish within a group provides information about how peaceful or confrontational they are with each other. Too much aggression can lead to stress and injury and affect the welfare of the fish. It is important that the aggressive behaviour of the fish remains within acceptable limits to ensure fish welfare (Ashley, 2007; Ellis et al., 2002; Magnhagen, 2015; Martins et al., 2012; Noble et al., 2020). For this reason, it is important to keep the "Aggression" parameter within this module. The weight of this parameter (PW) was set at 3.5 out of 5.

Territoriality: The territorial behaviour of fish provides information on how they mark and defend their habitat within a group. Too much territorial behaviour can lead to stress and injury and affect fish welfare. It is important that fish territorial behaviour remains within acceptable limits to ensure fish welfare (Ashley, 2007; Ellis et al., 2002; Magnhagen, 2015; Martins et al., 2012; Noble et al., 2020). For this reason, it is important to keep the "Territoriality" parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Scratching: Fish scratching objects in a fish tank can be a sign of stress or discomfort. It can be a sign of an injury or other health problem. It is important that fish scratching is monitored, and appropriate action taken to ensure fish welfare (Kleingeld et al., 2016; Martins et al., 2012; North et al., 2008). For this reason, it is important to keep the "Scratching" parameter within this module. The weight of this parameter (PW) was set at 4 out of 5.

Apathy: Fish that are behaving apathetically may be stressed or ill. It is important that fish behaviour is monitored, and appropriate action taken to ensure fish welfare (Kleingeld et al., 2016; Martins et al., 2012; Noble et al., 2020). For this reason, it is important to keep the "Apathy" parameter within this module. The weight of this parameter (PW) was set at 5 out of 5.

Isolation: Fish that isolate themselves from the group could be stressed or ill. It is important that fish behaviour is monitored, and appropriate action taken to ensure fish welfare (Kleingeld et al., 2016; Martins et al., 2012; Noble et al., 2020). For this reason, it is important to keep the "Isolation" parameter within this module. The weight of this parameter (PW) was set at 3.5 out of 5.

Surfacing: Fish gasping at the surface can be a sign of oxygen starvation or stress. It is important that fish behaviour is monitored, and appropriate action taken to ensure fish welfare (Kleingeld et al., 2016; Martins et al., 2012; Noble et al., 2020). For this reason, it is important to keep the "Surfacing" parameter within this module. The weight of this parameter (PW) was set at 4 out of 5.

Air gulping: Abnormal swimming patterns or surfacing of fish can be a sign of stress or discomfort. It is important that fish behaviour is monitored, and appropriate action taken to ensure fish welfare. The gulping of air at the surface is an indication of breathing impairments either caused by a malfunction of the gills or low oxygen concentrations in the system water (Noble et al., 2020; Noga, 2010; North et al., 2008). For this reason, it is important to keep the “Air gulping” parameter within this module. The weight of this parameter (PW) was set at 4 out of 5.

Ventilation rate: The ventilation rate of fish indicates how often they take a breath. An increased ventilation rate can be a sign of stress or a health problem (Noble et al., 2020; Noga, 2010; North et al., 2008). For this reason, it is important to keep the “Ventilation rate” parameter within this module. The weight of this parameter (PW) was set at 4 out of 5.

Fleeing: Fish fleeing behaviour indicates how they respond to threats or stress. Increased fleeing behaviour can be a sign of stress or discomfort (Davis, 2010; Kleingeld et al., 2016; Martins et al., 2012). For this reason, it is important to keep the “Fleeing” parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Fin position: The positions of the fins on the fish can give an indication of how stressed or relaxed they are(Davis, 2010; Kleingeld et al., 2016; Martins et al., 2012). For this reason, it is important to keep the “Fin position” parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Balance: The body balance of fish gives information about how well they are oriented in the water and how well they can move. Impaired body balance can be a sign of stress or a health problem (Davis, 2010; Macintyre, 2008). For this reason, it is important to keep the “Balance” parameter within this module. The weight of this parameter (PW) was set at 4.5 out of 5.

Body color: The body colouration of fish can give an indication of how healthy they are. Discoloration of the fish can be a sign of stress or a health problem (Noga, 2010; North et al., 2008; Segner et al., 2019). For this reason, it is important to keep the “Body colour” parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Feeding: The eating behaviour of fish gives information about how well they eat and how healthy they are. A change in eating habits can be a sign of stress or a health problem. Fish in husbandry should feed eagerly. Lack of feeding behaviour (covered with the parameter "apathy" and "isolation") or overly hectic and aggressive feeding are indicators of suboptimal feeding conditions or impaired health and welfare. Feeding behaviour is fish species and life stage specific and is subject to quotidian and seasonal changes. These aspects have to be considered when defining deviations for "normal" feeding behaviour (Martins et al., 2012; Noble et al., 2020; North et al., 2008). For this reason, it is important to keep the “Feeding” parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Jaw deformations Jaw deformities can indicate stress or a health problem. Deformations may inflict pain and or restrict movement and biological processes like breathing and feeding which affect fish welfare (Kestemont et al., 2007; North et al., 2008; Rodger & Phelps, 2015). For this reason, it is important to keep the "Jaw deformations" parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Gill cover deformations: Gill cover deformations can be a sign of stress or a health problem (Kestemont et al., 2007; North et al., 2008; Rodger & Phelps, 2015). For this reason, it is important to keep the "Gill cover deformations" parameter within this module. The weight of this parameter (PW) was set at 2 out of 5.

Spinal deformations: Spinal deformities can indicate stress or a health problem (Kestemont et al., 2007; North et al., 2008; Rodger & Phelps, 2015). For this reason, it is important to keep the "Spinal deformations" parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Eye injuries: Eye injuries can indicate stress or a health problem. Injuries provable inflict pain on fish. Moreover, injuries can restrict movement and biological processes like breathing and feeding which affect fish welfare (Ashley & Sneddon, 2008; Noble et al., 2012). For this reason, it is important to keep the "Eye injuries" parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Skin injuries: Skin injuries can indicate stress or a health problem. Besides the effects of injuries on feeling pain and restrictions of important functions of the fish body, a skin injury opens access to the inside of the fish for bacteria, viruses, and fungi which lead to infections. Infections have a direct impact on the fish's health and welfare (Ashley & Sneddon, 2008; Noble et al., 2012). For this reason, it is important to keep the "Skin injuries" parameter within this module. The weight of this parameter (PW) was set at 4 out of 5.

Fin injuries: Fin injuries can indicate stress or a health problem. Injuries provable inflict pain on fish. Fin injuries have a direct impact on the moving ability or restrictions of the body movements which affect fish welfare. For this reason, it is important to keep the "Fin injuries" parameter within this module (Ashley & Sneddon, 2008; Noble et al., 2012). The weight of this parameter (PW) was set at 3 out of 5.

Fungal infections: Fungal infections can affect the welfare of fish and is a common problem in fish farms. Infections of the fish's body with fungi or moulds affect the health and welfare of fish (Kleingeld et al., 2016; Meyer, 1991; Noga, 2010). For this reason, it is important to keep the "Fungal infections" parameter within this module. The weight of this parameter (PW) was set at 4 out of 5.

	Literature	Remarks	Parameter question	Location System Species	Parameter	Parameter intervals	PS	SW	PW	SWE PWE
Fish group behaviour	Wang et al., 2021; Schreck 1981; Ellis et al. 2002; Ashley 2007; Martins et al. 2012; Magnhagen 2015; Noble et al. 2020	Dominant (e.g. fin or opercula spreading, approaching) and aggressive (e.g. biting, bumping) behaviours can be costly for both the dominant and submissive individuals, causing stress and potential injuries that threaten the welfare of the fish.	Is aggressive behaviour detectable when observing the fish group?	In / Out RAS / FTS EP	Aggression	0: No fish shows dominance or aggression	0	1	3.5	1.7 1.7
						1: Individual fish show dominance behavior	-0.2	1.8		
						2: Some fish show dominance behavior	-0.4	2.6		
						3: Individual fish show aggression behavior	-0.6	3.4		
						4: Some fish show aggressive behavior	-0.8	4.2		
						5: Many fish are either dominant or aggressive	-1	5		
		Territorial behaviour can lead to aggression and if certain key areas (such as inlets, feeders, shelters, and shading) are monopolized, it may further undermine the health and welfare of certain fish by preventing their access to these resources.	Is territorial behaviour detectable when observing the fish group?	In / Out RAS / FTS EP	Territoriality	0: No fish shows territorial behavior	0	1	3	
						1: Individual fish show territorial behavior	-0.2	1.8		
						2: Some fish show territorial behavior	-0.4	2.6		
						3: Individual fish show a territorial monopolization of key areas	-0.6	3.4		
						4: Some fish show a territorial monopolization of key areas	-0.8	4.2		
						5: Some fish show a territorial monopolization of key areas, a large part of the shoal has no access to these areas	-1	5		
	North et al. 2008; Martins et al. 2012; Kleingeld et al. 2016	Jumping out of the water and/or scratching the body on surfaces (often visible as "flashing" when the brighter ventral side of the fish is briefly exposed) are signs of discomfort that are often caused by pathogens and indicate reduced health and welfare.	Is scratching detectable when observing the fish group?	In / Out RAS / FTS EP	Scratching	0: No fish jumps or scratches	0	1	4	
						1: Individual fish occasionally jump and/or scratch themselves on surfaces	-0.2	1.8		
						2: Some fish occasionally jump and/or scratch themselves on surfaces	-0.4	2.6		
						3: Individual fish frequently jump and/or scratch themselves on surfaces	-0.6	3.4		
						4: Some fish frequently jump and/or scratch themselves on surfaces	-0.8	4.2		
						5: Many fish frequently jump and/or scratch themselves on surfaces	-1	5		
	Davis 2010; Martins et al. 2012; Kleingeld et al. 2016; Noble et al. 2020	Apathy, or the lack of behaviours (e.g. feeding or swimming), especially in response to external stimuli (e.g. fleeing), is a sign of impaired health and welfare.	Is apathic behavior detectable when observing the fish group?	In / Out RAS / FTS EP	Apathy	0: No fish show signs of apathy	0	1	5	
						1: Individual fish show apathetic swimming behavior, react normally to stimulation	-0.2	1.8		
						2: Some fish show apathetic swimming behavior, react normally to stimulation	-0.4	2.6		
						3: Individual fish show apathetic swimming behavior, do not react to stimulation	-0.6	3.4		
						4: Some fish show apathetic swimming behavior, do not respond to stimulation	-0.8	4.2		
						5: Many fish show apathetic swimming behavior, do not respond to stimulation	-1	5		
		Fish separating themselves from the group is often a result of social or physiological stress and can indicate impaired health and/or welfare.	Is isoloating behavior detectable when observing the fish group?	In / Out RAS / FTS EP	Isolation	0: All fish are part of a shoal	0	1	3.5	
						1: Individual fish stand apart	-0.2	1.8		
						2: Some fish stand apart	-0.4	2.6		
						3: Individual fish stand apart and/or on the surface	-0.6	3.4		
						4: Some fish stand apart and/or on the surface	-0.8	4.2		
						5: Many fish stand apart and/or on the surface	-1	5		
		Abnormal swimming patterns (e.g. lying on the bottom or drifting at the surface) can indicate social (submissive/avoiding behaviour) or physiological (buoyancy problems, pain) issues. This parameter is specific to the species of fish, as different fish use the water column differently. The parameter and its intervals should be adjusted as needed to reflect the specific species being raised.	Where in the water column are the fish?	In / Out RAS / FTS EP	Surfacing	0: All fish swim normally in the water column	0	1	4	
						1: Individual fish are predominantly lying on the bottom	-0.2	1.8		
						2: Some fish are constantly lying on the bottom	-0.4	2.6		
						3: Individual fish are increasingly swimming on the surface	-0.6	3.4		
						4: Some fish swim mainly on the surface	-0.8	4.2		
						5: Many fish swim mainly on the surface	-1	5		

	Literature	Remarks	Parameter question	Location System Species	Parameter	Parameter intervals	PS	SW	PW	SWE PWE
Fish group behaviour	Carballo et al., 2008; Ekström et al., 2016; North et al. 2008; Noga 2010; Noble et al. 2020	Gulping air at the surface is a sign of impaired breathing, which can be caused by either a malfunction of the gills or low oxygen concentrations in the water.	Is air gulping detectable when observing the fish group?	In / Out RAS / FTS EP	Air gulping	0: No fish shows air breathing	0	1	4	
						1: Individual fish show occasional gasps	-0.2	1.8		
						2: Some fish show occasional gasps	-0.4	2.6		
						3: Individual fish show frequent gasps	-0.6	3.4		
						4: Some fish show constant air gulping	-0.8	4.2		
						5: Many fish show constant air gulping	-1	5		
		Chronic changes in ventilation, such as increased or decreased rates or intensities of opercula movements, can indicate chronic stress and poor health. It's important to take into account the effects of acute stressors, such as feeding time or external disturbances, when determining what is considered 'normal' ventilation behaviour.	Is the ventilation rate normal?	In / Out RAS / FTS EP	Ventilation rate	0: All fish have a normal ventilation rate	0	1	4	
						1: Individual fish show an increased ventilation rate	-0.2	1.8		
						2: Some fish show increased ventilation rate	-0.4	2.6		
						3: Individual fish show a greatly increased or slightly reduced ventilation rate	-0.6	3.4		
						4: Some fish show a greatly increased or clearly reduced ventilation rate	-0.8	4.2		
						5: Many fish show a greatly increased or clearly reduced ventilation rate	-1	5		
	Davis 2010; Martins et al. 2012 ; Kleingeld et al. 2016	Fleeing behaviour is a normal response for most fish species. If a fish exhibits a prolonged or absent reaction to external stimuli, it may be a sign of poor health and welfare.	Is the fleeing behaviour normal?	In / Out RAS / FTS EP	Fleeing	0: All fish show normal fleeing when stimulated and calm down quickly	0	1	3	
						1: Individual fish show an increased and/or prolonged fleeing behavior	-0.2	1.8		
						2: Some fish show an increased and/or prolonged fleeing behavior	-0.4	2.6		
						3: Individual fish show no or constant fleeing behavior	-0.6	3.4		
						4: Some fish show no or constant fleeing behavior	-0.8	4.2		
						5: Many fish show no or constant fleeing behavior	-1	5		
		An unusual position of the fins may indicate social or physiological stress. The normal position of fins may vary by species, so it is important to consider this when evaluating abnormal behaviours.	Is the fin position normal?	In / Out RAS / FTS EP	Fin position	0: All fish show a normal and calm fin position	0	1	3	1.7 1.7
						1: Individual fish occasionally have their fins pinched or splayed out	-0.2	1.8		
						2: Some fishes occasionally pinch or splay out their fins	-0.4	2.6		
						3: Individual fishes have the fins constantly pinched or splayed out	-0.6	3.4		
						4: Some fish have the fins constantly pinched or splayed out	-0.8	4.2		
						5: Many fishes have the fins constantly pinched or splayed out	-1	5		
	Lee 1893; MacIntyre et al. 2008; Davis 2010	Fish should be able to maintain an upright body position and proper orientation in the water column at all times. Struggles or inability to do so may indicate physiological issues.	Do the fish have good balance?	In / Out RAS / FTS EP	Balance	0: All fish show a normal balance and orientation	0	1	4.5	
						1: Individual fish are sometimes misaligned	-0.2	1.8		
						2: Some fish are crooked at times	-0.4	2.6		
						3: Individual fish are constantly crooked	-0.6	3.4		
						4: Some fish are constantly crooked	-0.8	4.2		
						5: Many fish are constantly crooked	-1	5		
	Ferguson 2008; North et al. 2008; Noga 2010; Segner et al. 2019	Changes in body coloration, such as paleness or darkening, can indicate social or physiological stress. The specific body coloration of a fish can vary by species and life stage, and may also be affected by seasonal changes. It's important to take these factors into account when determining what is considered 'normal' body coloration.	Are the fish coloured normally?	In / Out RAS / FTS EP	Body color	0: All the fish show a normal body coloration	0	1	3	
						1: Single fish have temporarily a conspicuously bright or dark coloration	-0.2	1.8		
						2: Some fish have temporarily a conspicuously bright or dark coloration	-0.4	2.6		
						3: Individual fish have constantly striking a bright or dark coloration	-0.6	3.4		
						4: Some fish constantly have a noticeable light or dark color	-0.8	4.2		
						5: Many fish constantly have a noticeable light or dark color	-1	5		
	North et al. 2008; Martins et al. 2012; Noble et al. 2020	Fish in captivity should show eagerness to feed. A lack of feeding behaviour (which may be indicated by apathy or isolation) or excessively frenzied and aggressive feeding can be signs of suboptimal feeding conditions or poor health and welfare. It's important to note that feeding behaviour can vary by species and life stage, and may also be influenced by daily and seasonal changes. These factors should be taken into consideration when determining what is considered 'normal' feeding behaviour.	Is the feeding behavior expressed normally?	In / Out RAS / FTS EP	Feeding	0: All fish show normal feeding behavior	0	1	3	
						1: Individual fish show a very hungry, hectic eating behavior	-0.2	1.8		
						2: Some fish show a very hungry, hectic eating behavior	-0.4	2.6		
						3: Individual fish show a starved, aggressive eating behavior	-0.6	3.4		
						4: Some fish show a starved, aggressive eating behavior	-0.8	4.2		
						5: Many fish show a starved, aggressive eating behavior	-1	5		

	Literature	Remarks	Parameter question	Location System Species	Parameter	Parameter intervals	PS	SW	PW	SWE PWE
Fish group behaviour	Kestemont et al. 2007; North et al. 2008; Rodger & Phelps 2015; Policar et al. 2016	Deformities can cause pain and/or limit movement, breathing, and feeding, which can negatively impact fish health and welfare. Knowing how many fish are affected, as well as when and how quickly the deformities appeared, can help identify their causes and potential remediation measures.	How many fish have jaw deformations?	In / Out RAS / FTS EP	Jaw deformations	0: No fish has injuries/deformations of the jaw/snout	0	1	3	1.7 1.7
						1: Individual fish have slight injuries/deformations of the jaw/snout	-0.2	1.8		
						2: Some fish have slight injuries/deformations of the jaw/snout	-0.4	2.6		
						3: Individual fish have severe injuries/deformations of the jaw/snout	-0.6	3.4		
						4: Some fish have severe injuries/deformations of the jaw/snout	-0.8	4.2		
						5: Many fish have severe injuries/deformations of the jaw/snout	-1	5		
			How many fish have opercula deformations?	In / Out RAS / FTS EP	Gill cover deformations	0: No fish has injuries/deformations of the opercula	0	1	2	
						1: Individual fish have slight injuries/deformations of the opercula	-0.2	1.8		
						2: Some fish have slight injuries/deformations of the opercula	-0.4	2.6		
						3: Individual fish have severe injuries/deformations of the opercula	-0.6	3.4		
						4: Some fish have severe injuries/deformations of the opercula	-0.8	4.2		
						5: Many fish have severe injuries/deformations of the opercula	-1	5		
			How many fish have spinal deformations?	In / Out RAS / FTS EP	Spinal deformations	0: No fish has injuries/deformations of the spine	0	1	3	
						1: Individual fish have a slight injuries/deformations of the spine	-0.2	1.8		
						2: Some fish have a slight injuries/deformations of the spine	-0.4	2.6		
						3: Individual fish have a severe injuries/deformations of the spine	-0.6	3.4		
						4: Some fish have severe injuries/deformations of the spine	-0.8	4.2		
						5: Many fish have a severe injuries/deformations of the spine	-1	5		
	Ashley & Sneddon 2008; Noble et al. 2012	Injuries can cause pain and/or limit movement, breathing, and feeding, which can negatively impact fish health and welfare. Knowing how many fish are affected, as well as when and how quickly the injuries appeared, can help identify their causes and potential remediation measures.	How many fish have eye injuries?	In / Out RAS / FTS EP	Eye injuries	0: No fish has eye injuries/deformations	0	1	3	
						1: Individual fish have slight injuries/deformations to the eyes	-0.2	1.8		
						2: Some fish have minor eye injuries/deformations	-0.4	2.6		
						3: Individual fish have severe injuries/deformations to the eyes	-0.6	3.4		
						4: Some fish have severe eye injuries/deformations	-0.8	4.2		
						5: Many fish have severe injuries/deformations to the eyes	-1	5		
			How many fish have skin injuries?	In / Out RAS / FTS EP	Skin injuries	0: No fish has injuries/deformations of the skin	0	1	4	
						1: Individual fish have slight injuries/deformations of the skin	-0.2	1.8		
						2: Some fish have slight injuries/deformations of the skin	-0.4	2.6		
						3: Individual fish have severe injuries/deformations of the skin	-0.6	3.4		
						4: Some fish have severe injuries/deformations of the skin	-0.8	4.2		
						5: Many fish have severe injuries/deformations of the skin	-1	5		
			How many fish have fin injuries?	In / Out RAS / FTS EP	Fin injuries	0: No fish has injuries/deformations of the fins	0	1	3	
						1: Individual fish have slight injuries/deformations of the fins	-0.2	1.8		
						2: Some fish have slight injuries/deformations of the fins	-0.4	2.6		
						3: Individual fish have severe injuries/deformations of the fins	-0.6	3.4		
						4: Some fish have severe injuries/deformations of the fins	-0.8	4.2		
						5: Many fish have severe injuries/deformations of the fins	-1	5		
	Meyer 1991; Noga 2010; Kleingeld et al. 2016	Infections of the body and fins with fungi or mold can indicate poor health and welfare. Knowing how many fish and which body parts are affected, as well as when and how quickly the infection appeared, can help identify its causes and potential remediation measures.	How many fish have fungal or mould infections?	In / Out RAS / FTS EP	Fungal infections	0: No fish has any fungus	0	1	4	
						1: Individual fish have fungal infection of the fins	-0.2	1.8		
						2: Some fish have fungal infection of the fins	-0.4	2.6		
						3: Individual fish have fungal infection of the fins and the body	-0.6	3.4		
						4: Some fish have fungal infection of the fins and the body	-0.8	4.2		
						5: Many fish have fungal infection of the fins and the body	-1	5		

10. Appendix D: Fish morphology parameters

Cataract: Clouding or discoloration of the eyes can be a sign of stress or illness in fish. It can be caused by injury or inflammation. It is important to determine the cause of eye cloudiness and take appropriate action to improve fish welfare (Ferguson, 2006; Kleingeld et al., 2016; Noble et al., 2020; Noga, 2010; North et al., 2008; Pettersen et al., 2014; Rodger & Phelps, 2015). For this reason, it is important to keep the "Cataract" parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Eye injury: Eye injuries can be the result of stress or illness but can be caused by mechanical injuries such as bumping into objects in the fish farm. It is important to treat such injuries quickly to prevent further damage and improve fish welfare (Ferguson, 2006; Kleingeld et al., 2016; Noble et al., 2020; Noga, 2010; Pettersen et al., 2014; Rodger & Phelps, 2015). For this reason, it is important to keep the "Eye injury" parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Exophthalmia: Exophthalmia, known as bulging eyes, can be caused by disease or injury. It is important to determine the cause of the exophthalmia and take appropriate action to improve fish welfare (Ferguson, 2006; Kleingeld et al., 2016; Noble et al., 2020; Noga, 2010; Pettersen et al., 2014; Rodger & Phelps, 2015). For this reason, it is important to keep the "Exophthalmia" parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Pectoral fins: The pectoral fins are the paired fins on the side of the fish's body that help them propel themselves through the water. Injuries to these fins can affect the welfare of the fish and should therefore be treated to prevent further damage (Bosakowski & Wagner, 1994; Hoyle et al., 2007; Policar et al., 2016). For this reason, it is important to keep the "Pectoral fins" parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Ventral fins: The ventral fins are the paired fins under the fish's body that help them propel themselves through the water. Injuries to these fins can affect the welfare of the fish and should therefore be treated to prevent further damage (Bosakowski & Wagner, 1994; Hoyle et al., 2007; Policar et al., 2016). For this reason, it is important to keep the "Ventral fins" parameter within this module. The weight of this parameter (PW) was set at 2 out of 5.

Anal fins: The anal fin is the fin on the anus of the fish that helps them move in the water. Injuries to this fin can affect the welfare of the fish and should therefore be treated to prevent further damage (Bosakowski & Wagner, 1994; Hoyle et al., 2007; Policar et al., 2016). For this reason, it is important to keep the "Anal fins" parameter within this module. The weight of this parameter (PW) was set at 2 out of 5.

Caudal fin: The caudal fin, known as the caudal fin, is the fin at the end of the fish's body that helps them propel themselves through the water. Injuries to this fin can affect the welfare of the fish and should therefore be treated to prevent further damage (Bosakowski & Wagner, 1994; Hoyle et al., 2007; Policar et al., 2016). For this reason, it is important to keep the “Caudal fin” parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Dorsal fin: The dorsal fin is the fin on the back of the fish that helps them propel themselves and balance in the water. Injuries to this fin can affect the welfare of the fish and should therefore be treated to prevent further damage (Bosakowski & Wagner, 1994; Hoyle et al., 2007; Policar et al., 2016). For this reason, it is important to keep the “Dorsal fin” parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Body condition factor: The body condition factor is a measure of the state of health of the fish. It is determined by the ratio of body mass to body length and can be used to assess the welfare of fish on a fish farm. A low Body Condition Factor may indicate that the fish are suffering from stress or malnutrition, while a high Body Condition Factor indicates good health and welfare (Molnár et al., 2006; Steinberg et al., 2017; Zakęś et al., 2012). For this reason, it is important to keep the “Body condition factor” parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Spinal deformation: Injuries to the spine can affect the well-being of fish, leading to pain and reduced mobility. It is important to treat such injuries quickly to prevent further damage and improve fish welfare (Ashley, 2007; E. J. Branson, 2008; Noble et al., 2012; Rodger & Phelps, 2015). For this reason, it is important to keep the “Spinal deformation” parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Jaw deformation: Jaw deformities can affect the well-being of fish and limit their ability to ingest and process food. It is important to treat such deformations quickly to prevent further damage and improve fish welfare (Ashley, 2007; E. J. Branson, 2008; Noble et al., 2012; Rodger & Phelps, 2015). For this reason, it is important to keep the “Jaw deformation” parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Mouth injury: Mouth injuries can affect the well-being of fish and limit their ability to ingest and process food. It is important to treat such injuries quickly to prevent further damage and improve fish welfare (Ashley, 2007; E. J. Branson, 2008; Noble et al., 2012, 2020; Rodger & Phelps, 2015). For this reason, it is important to keep the “Mouth injury” parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Mucus pathogens: The presence of parasites in fish slime can affect the well-being of fish, leading to pain and reduced mobility. It is important to treat such parasites quickly to prevent further damage and improve fish welfare (Ferguson, 2006; Noga, 2010; North et al., 2008). For this reason, it is important to keep the "Mucus pathogens" parameter within this module. The weight of this parameter (PW) was set at 4 out of 5.

Skin alterations: Changes in the skin, such as flaking or discoloration, can be a sign of stress or illness in fish. It is important to determine the cause of such changes and take appropriate action to improve fish welfare (Ferguson, 2006; Kleingeld et al., 2016; Noble et al., 2012; North et al., 2008). For this reason, it is important to keep the "Skin alterations" parameter within this module. The weight of this parameter (PW) was set at 3.5 out of 5.

Skin fungus and Skin injury: Skin fungi and injuries to the skin can affect the well-being of fish and lead to pain and restricted mobility. It is important to treat such fungi and injuries quickly to prevent further damage and improve fish welfare (Ferguson, 2006; Kleingeld et al., 2016; Noble et al., 2012; Rodger & Phelps, 2015). For this reason, it is important to keep the "Skin fungus" and "Skin injury" parameter within this module. The parameter (PW) of skin fungus was set at 4 out of 5 and the PW of skin injury was set at 3.5 out of 5.

Gill cover: The gill covers, are the scales that protect the fish's gills. Injury or deformation of the gill cover can affect fish welfare and limit their ability to absorb oxygen from the water. It is important to treat such injuries or deformities quickly to prevent further damage and improve fish welfare (Noble et al., 2020; Pettersen et al., 2014). For this reason, it is important to keep the "Gill cover" parameter within this module. The weight of this parameter (PW) was set at 2 out of 5.

Gills: The condition of the gills is an important indicator of fish welfare. Injury or discoloration of the gills can indicate stress or illness and should be treated promptly to prevent further damage and improve fish welfare (Ferguson, 2006; North et al., 2008; Pettersen et al., 2014). For this reason, it is important to keep the "Gills" parameter within this module. The weight of this parameter (PW) was set at 5 out of 5.

	Literature	Remarks	Parameter question	Location System Species	Parameter	Parameter intervals	PS	SW	PW	SWE PWE
Fish external appearance	Ferguson 2006; North et al. 2008; Noga 2010; Pettersen et al. 2014; Rodger & Phelps 2015; Kleingeld et al. 2016; Noble et al. 2020	The eye is a vital organ, and any damage to it can impact fish health and welfare. The causes and effects of different eye damages can vary depending on the nature of the damage, which is why cataracts, bleedings, injuries, and exophthalmia are treated as separate parameters. Identifying and distinguishing these different types of eye damage can help assess the impact on health and welfare, and assist in identifying causes and potential remediation measures. While the pain or discomfort caused by eye damage may be similar among fish, the effects of impaired vision can vary by species, with visual predators and highly social species likely to be more affected.	Does the fish have clouding of the eye lens?	In / Out RAS / FTS EP	Cataract	0: Both eyes are clear	0	1	3	1.7 1.7
						1: One lens shows light clouding	-0.33	2.33		
						2: Both lenses show light clouding or one lens strong clouding	-0.66	3.66		
						3: Both lenses show strong clouding	-1	5		
			Does the fish have an injury of the eye?	In / Out RAS / FTS EP	Eye injury	0: No indication	0	1	3	
						1: One-sided small injury, not inflamed or healing	-0.33	2.33		
						2: One-sided injury or both-sided small injury, slightly inflamed	-0.66	3.66		
						3: One-sided severe injury or both-sided injury, inflamed	-1	5		
			Does the fish have bulging of the eye?	In / Out RAS / FTS EP	Exophthalmia	0: No indication	0	1	3	
						1: One-sided slight exophthalmia	-0.33	2.33		
						2: Both-sided slight exophthalmia or one-sided exophthalmia	-0.66	3.66		
						3: Both-sided exophthalmia	-1	5		
	Branson 2008; Bosakowski & Wagner 1994; Hoyle et al. 2007; Policar et al. 2016	The fins are important for movement and communication, and any damage to them can impact fish health and welfare. The causes and effects of different fin damages can vary depending on the nature of the damage (such as rotting, erosion, abrasion, or bites) and the location of the damage (e.g. pectoral, ventral, anal, caudal, or dorsal fins). As a result, each type of fin damage is treated as a separate parameter. Identifying and distinguishing these different types of fin damage can help assess the impact on health and welfare, and assist in identifying causes and potential remediation measures.	Does the fish have damages or deformations of the pectoral fins?	In / Out RAS / FTS EP	Pectoral fins	0: Undamaged fins	0	1	3	
						1: One-sided/both-sided: indications of scar tissue or small/active fin damage	-0.33	2.33		
						2: One-sided/both-sided: active fin damage or indications of fungal infections and/or inflammation	-0.66	3.66		
						3: Both-sided: extensive scar tissue and/or extensive active fin damage (with/without inflammation) or extensive fungal infection or fin loss	-1	5		
			Does the fish have damages or deformations of the ventral fins?	In / Out RAS / FTS EP	Ventral fins	0: Undamaged fins	0	1	2	
						1: One-sided/both-sided: indications of scar tissue or small/active fin damage	-0.33	2.33		
						2: One-sided/both-sided: active fin damage or indications of fungal infections and/or inflammation	-0.66	3.66		
						3: Both-sided: extensive scar tissue and/or extensive active fin damage (with/without inflammation) or extensive fungal infection or fin loss	-1	5		
			Does the fish have damages or deformations of the anal fin?	In / Out RAS / FTS EP	Anal fin	0: Undamaged fin	0	1	2	
						1: Indications of scar tissue or small and active fin damage	-0.33	2.33		
						2: Active fin damage or indications of fungal infections and/or inflammation	-0.66	3.66		
						3: Extensive scar tissue and/or extensive active fin damage (with/without inflammation) or extensive fungal infection or fin loss	-1	5		
			Does the fish have damages or deformations of the caudal fin?	In / Out RAS / FTS EP	Caudal fin	0: Undamaged fin	0	1	3	
						1: Indications of scar tissue or small and active fin damage	-0.33	2.33		
						2: Active fin damage or indications of fungal infections and/or inflammation	-0.66	3.66		
						3: Extensive scar tissue and/or extensive active fin damage (with/without inflammation) or extensive fungal infection or fin loss	-1	5		
			Does the fish have damages or deformations of the dorsal fin?	In / Out RAS / FTS EP	Dorsal fin	0: Undamaged fin	0	1	3	
						1: Indications of scar tissue or small and active fin damage	-0.33	2.33		
						2: Active fin damage or indications of fungal infections and/or inflammation	-0.66	3.66		
						3: Extensive scar tissue and/or extensive active fin damage (with/without inflammation) or extensive fungal infection or fin loss	-1	5		

	Literature	Remarks	Parameter question	Location System Species	Parameter	Parameter intervals	PS	SW	PW	SWE PWE
Fish external appearance	Molnar et al. 2006; Zakęś et al. 2012; Steinberg et al. 2017	The body condition factor, which is a ratio of weight to length, is a useful indicator of fish health and welfare that reflects mid- and long-term effects of suboptimal husbandry conditions. It is important to note that the optimal and tolerance values for the body condition factor can vary by fish species and life stage, and are influenced by the basic body shape of the fish. These factors should be taken into consideration when interpreting this parameter.	Fulton's condition factor K [bodyweight/ standardlength^3 x 100]	In / Out RAS / FTS EP	Body condition factor	0: 0.9 - 1.1 1: 0.7 - 1.3 2: > 1.3 3: < 0.7	0 -0.33 -0.66 -1	1 2.33 3.66 5	3	
	Ashley 2007; Branson & Turnbull 2008; Noble et al. 2012, 2020; Rodger & Phelps 2015	Spinal deformities can cause pain and/or limit movement, which can impact feeding, behaviour, and overall health and welfare of the fish.	Does the fish have spinal deformations?	In / Out RAS / FTS EP	Spinal deformation	0: No indication 1: Indication of deformation 2: Clear deformation 3: Strong deformation	0 -0.33 -0.66 -1	1 2.33 3.66 5	3	
		Jaw deformities can cause pain and/or impair feeding and breathing, which can negatively impact the health and welfare of the fish.	Does the fish have deformations of the lower or upper jaw?	In / Out RAS / FTS EP	Jaw deformation	0: No indication 1: Indication of deformation 2: Clear deformation 3: Strong deformation	0 -0.33 -0.66 -1	1 2.33 3.66 5	3	
		Injuries to the mouth and jaws can cause pain and/or impair feeding and breathing, which can negatively impact the health and welfare of the fish.	Does the fish have an injury on the mouth?	In / Out RAS / FTS EP	Mouth injury	0: No indication 1: A few small injuries 2: Several small injuries 3: One or more large/deep injuries	0 -0.33 -0.66 -1	1 2.33 3.66 5	3	
	Ferguson 2006; North et al. 2008; Noga 2010	External pathogens such as parasites, fungi, mold, and bacteria can generally harm fish health and welfare. Semi-quantitatively assessing the parasite load in the mucus can help evaluate the health of the fish, track countermeasures, and identify problems early.	Are parasites visible in a mucus swop under a 40-100 fold magnification?	In / Out RAS / FTS EP	Mucus pathogens	0: No parasites detectable 1: A few parasites 2: Considerable parasite load 3: Heavy parasite load	0 -0.33 -0.66 -1	1 2.33 3.66 5	4	1.7 1.7
	Ferguson 2006; North et al. 2008; Noble et al. 2012; Rodger & Phelps 2015; Kleingeld et al. 2016	The skin serves as a major barrier between the fish and its environment, and any damage to it can impact fish health and welfare. The causes and effects of different skin damages can vary depending on the nature of the damage, which is why alterations, fungal infections, bleedings, injuries, and scale loss are treated as separate parameters. Identifying and distinguishing these different types of skin damage can help assess the impact on health and welfare, and assist in identifying causes and potential remediation measures.	Does the fish have alterations of the skin?	In / Out RAS / FTS EP	Skin alterations	0: No indication 1: A few small alterations (tumors, swellings, rashes, bleedings) 2: Several small alterations (tumors, swellings, rashes, bleedings) 3: One or more large alterations (tumors, swellings, rashes, bleedings)	0 -0.33 -0.66 -1	1 2.33 3.66 5	3.5	
			Does the fish have fungi or moulds on the skin? (fins are excluded)	In / Out RAS / FTS EP	Skin fungus	0: No indication 1: A few small areas infected 2: Several small areas infected 3: One or more large areas infected	0 -0.33 -0.66 -1	1 2.33 3.66 5	4	
			Does the fish have an injury of the skin or loss of scales?	In / Out RAS / FTS EP	Skin injury	0: No indication 1: A few small injuries or small areas with scale loss 2: Several small injuries and/or small areas with scale loss 3: One or more large/deep injuries and/or areas with scale loss	0 -0.33 -0.66 -1	1 2.33 3.66 5	3.5	
	Pettersen et al. 2014; Noble et al. 2020	Injuries or deformations of the opercula can cause pain and impair breathing, which can negatively impact the health and welfare of the fish.	Does the fish have a damage or deformation of the gill cover/opercula?	In / Out RAS / FTS EP	Gill cover	0: Both-sided: undamaged opercula 1: One-sided/both-sided: opercula covers min. 2/3 of gill area 2: One-sided/both-sided: opercula covers min. 1/3 of gill area 3: One-sided/both-sided: opercula covers less than 1/3 of gill area	0 -0.33 -0.66 -1	1 2.33 3.66 5	2	
	Ferguson 2006; North et al. 2008; Pettersen et al. 2014	Injuries or alterations to the primary lamellae of the gills can cause pain and impair breathing, which can negatively impact the health and welfare of the fish.	Does the fish have damaged or discolored gills?	In / Out RAS / FTS EP	Gills	0: Both-sided: undamaged, red gills 1: One-sided/both-sided: indications of damaged and/or discolored gill tissue 2: One-sided/both-sided: several small areas of damaged and/or discolored gill tissue 3: One-sided/both-sided: extensive areas of damaged and/or discolored gill tissue	0 -0.33 -0.66 -1	1 2.33 3.66 5	5	

11. Appendix E: Fish anatomy parameters

Heart: The heart is an important organ for the blood circulation and oxygen supply of the fish. A healthy heart should be of normal size and shape and free from changes or abnormalities (Ashley, 2007; Ferguson, 2006; Noga, 2010; North et al., 2008; Pettersen et al., 2014). For this reason, it is important to keep the "Heart" parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Kidney: The kidneys are important in regulating the water and electrolyte balance of the fish. A healthy kidney should be of normal size and shape and free from changes or abnormalities (Ashley, 2007; Ferguson, 2006; Noga, 2010; North et al., 2008; Pettersen et al., 2014). For this reason, it is important to keep the "Kidney" parameter within this module. The weight of this parameter (PW) was set at 3.5 out of 5.

Spleen: The spleen is an important organ in the fish's immune system. A healthy spleen should be of normal size and shape and free from changes or abnormalities (Ashley, 2007; Ferguson, 2006; Noga, 2010; North et al., 2008; Pettersen et al., 2014). For this reason, it is important to keep the "Spleen" parameter within this module. The weight of this parameter (PW) was set at 4 out of 5.

Liver: The liver is an important metabolic organ involved in the processing of nutrients and waste products. A healthy liver should be of normal size and shape and free from changes or abnormalities (Ashley, 2007; Ferguson, 2006; Noga, 2010; North et al., 2008; Pettersen et al., 2014). For this reason, it is important to keep the "Liver" parameter within this module. The weight of this parameter (PW) was set at 4 out of 5.

Intestines: The fish's intestines, such as the intestines and stomach, play an important role in digestion and nutrient absorption. A healthy viscera should be of normal size and shape and free from changes or abnormalities (Ferguson, 2006; Noble et al., 2020; Pettersen et al., 2014). For this reason, it is important to keep the "Intestines" parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Muscles: Healthy muscles should be of normal size and shape and free from changes or abnormalities (Ferguson, 2006; Noga, 2010; Pettersen et al., 2014). For this reason, it is important to keep the "Muscles" parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Body cavity: The body cavity is the space inside the fish body that contains the internal organs. A healthy body cavity should be free from changes or abnormalities and show no signs of infection or inflammation (Noble et al., 2020; Noga, 2010; Rodger & Phelps, 2015). For this reason, it is important to keep the “Body cavity” parameter within this module. The weight of this parameter (PW) was set at 3 out of 5.

Reprouctive organs: Under farming conditions (except for reproduction) the development of the gonads and expression of spawning behaviour are usually not desired. Due to the additional stress and reduced immune system an active reproduction state is included as a welfare parameter. A healthy reproductive organ should be of normal size and shape and free from changes or abnormalities (Folkedal et al., 2016; North et al., 2008). For this reason, it is important to keep the “Reproductive organs” parameter within this module. The weight of this parameter (PW) was set at 2 out of 5.

Gill lamellae: The gill lamellae are the scales that protect the fish's gills. A healthy gill lamella should be of normal size and shape and free from changes or abnormalities (Ferguson, 2006; Noga, 2010; North et al., 2008). For this reason, it is important to keep the “Gill lamellae” parameter within this module. The weight of this parameter (PW) was set at 5 out of 5.

Gill pathogens: Gill pathogens are pathogens that can attack and infect the gills of fish. The presence of gill pathogens can affect fish welfare and should therefore be treated promptly to prevent further damage and improve fish welfare. For this reason, it is important to keep the “Gill pathogens” parameter within this module (Ferguson, 2006; Noga, 2010; North et al., 2008). The weight of this parameter (PW) was set at 4 out of 5.

	Literature	Remarks	Parameter question	Location System Species	Parameter	Parameter intervals	PS	SW	PW	SWE PWE
Fish internal appearance	Ferguson 2006; Ashley 2007; North et al. 2008; Noga 2010; Pettersen et al. 2014	Healthy and functioning organs are crucial for fish health and welfare. Each organ is treated as a separate parameter because impairments may be specific to certain organs. Understanding the exact nature of organ damage can help identify causes and potential remediation measures.	How does the fish's heart look like?	In / Out RAS / FTS EP	Heart	0: Inconspicuous	0	1	3	
						1: Slight discoloration	-0.33	2.33		
						2: Discolored and/or small necrosis and/or small hemorrhages	-0.66	3.66		
						3: Severely discolored and/or necrosis and/or hemorrhages	-1	5		
			How does the fish's kidney look like?	In / Out RAS / FTS EP	Kidney	0: Inconspicuous	0	1	3.5	
						1: Slight discoloration	-0.33	2.33		
						2: Discolored and/or slightly granular	-0.66	3.66		
						3: Severely discolored and/or granular	-1	5		
			How does the fish's spleen look like?	In / Out RAS / FTS EP	Spleen	0: Inconspicuous	0	1	4	
						1: Slight enlargement	-0.33	2.33		
						2: Discolored and/or slightly enlarged	-0.66	3.66		
						3: Severely discolored and/or enlarged	-1	5		
			How does the fish's liver look like?	In / Out RAS / FTS EP	Liver	0: Inconspicuous	0	1	4	
						1: Slight discoloration	-0.33	2.33		
						2: Discolored and/or slightly enlarged and/or small necrosis	-0.66	3.66		
						3: Severely discolored and/or enlarged and/or necrosis	-1	5		
	Ferguson 2006; Pettersen et al. 2014; Noble et al. 2020	A healthy intestine is both a sign of good nutrition and overall health in fish. Knowing the exact nature of any damage to the intestine can help identify causes and potential remediation measures.	How do the fish's stomach and intestines look like?	In / Out RAS / FTS EP	Intestines	0: Homogeneously filled with smooth food pulp	0	1	3	
						1: Unevenly filled with food pulp	-0.33	2.33		
						2: Indications of inflammation and change in tissue (discoloring, swelling, tumors)	-0.66	3.66		
						3: Inflammation and/or change in tissue (discolored and/or swollen tissue, tumors, hemorrhages, necrosis) or foreign objects	-1	5		
	Ferguson 2006; Noga 2010; Pettersen et al. 2014	Healthy muscles are essential for fish health and welfare. Determining the specific nature of muscle tissue damage can aid in identifying causes and potential remediation measures.	How does the fish's muscle tissue look like?	In / Out RAS / FTS EP	Muscles	0: Normal	0	1	3	1.7 1.7
						1: Single small hemorrhages, small vaccination damage	-0.33	2.33		
						2: Several small or single extensive hemorrhages and/or clear vaccination damage	-0.66	3.66		
						3: Extensive hemorrhages and/or necrosis and/or extensive vaccination damage	-1	5		
	Noga 2010; Rodger & Phelps 2015; Noble et al. 2020	A healthy body cavity is a sign of good health in fish. Understanding the specific nature of any damage to the body cavity can help identify causes and potential remediation measures.	How does the fish's body cavity look like?	In / Out RAS / FTS EP	Body cavity	0: Inconspicuous	0	1	3	
						1: Slight bleeding into the intestine and/or abdominal fat and/or swim bladder wall	-0.33	2.33		
						2: Bleeding into the intestine and/or abdominal fat and/or swim bladder wall / slight fluid accumulation	-0.66	3.66		
						3: Severe bleeding into the intestine and/or abdominal fat and/or swim bladder wall / fluid accumulation	-1	5		
	North et al. 2008; Wootton & Smith 2015; Folkedal et al. 2016	Under farming conditions (excluding reproduction), the development of the gonads and expression of spawning behaviour are typically not desired. This is because an active reproduction state can cause additional stress and weaken the immune system, which can negatively impact fish welfare. It's important to note that the intervals for this parameter and how it should be adapted for different fish species, life stages, and purposes of husbandry may vary..	How far are the ovaries or testes developed?	In / Out RAS / FTS EP	Repro-ductive organs	0: Not developed	0	1	2	
						1: Slightly developed/enlarged	-0.33	2.33		
						2: Developed/enlarged	-0.66	3.66		
						3: Ready to spawn	-1	5		
	Ferguson 2006; North et al. 2008; Noga 2010	Injuries or alterations to the secondary lamellae of the gills can cause pain and impair breathing, which can negatively impact the health and welfare of the fish.	How do the fish's secondary gill lamellae look like under a 40-100 fold magnification?	In / Out RAS / FTS EP	Gill lamellae	0: Normal	0	1	5	
						1: Lamellae slightly swollen	-0.33	2.33		
						2: Lamellae swollen, small hemorrhages and/or necrosis and/or edema and/or detachment of epithelium	-0.66	3.66		
						3: Lamellae severely swollen, hemorrhages and/or necrosis and/or endema and/or detachment of epithelium, extensive mucus	-1	5		
		External pathogens such as parasites, fungi, mold, and bacteria can generally harm fish health and welfare. Assessing the parasite load of the gills in a semi-quantitative way can help evaluate the health of the fish, track countermeasures, and identify problems early.	Are parasites visible in a gill sample under a 40-100 fold magnification?	In / Out RAS / FTS EP	Gill pathogens	0: No parasites detectable	0	1	4	
						1: A few parasites	-0.33	2.33		
						2: Considerable parasite load	-0.66	3.66		
						3: Heavy parasite load	-1	5		

12. Appendix F: SOP

Standard **O**perating **P**rocedure **SOP** for implementing a new fish species into MyFishCheck

12th January 2023

1. Defining phase
2. Data collecting phase
3. Data management phase
4. Testing phase
5. Go-live phase

I. Ensure that the key team members have the background necessary for the project:
   a. Understand the structure of the MyFishCheck model (https://doi.org/10.21256/zhaw-21290)
   b. Download and comprehend the function of the mobile app (https://www.myaquaculturefarm.ch/en/software.php)
   c. Read the bachelor thesis and SOP on how to implement new fish species into the MyFishCheck
   d. Identify the reason and purpose of implementing the given fish species in the model
   e. Characterise the context of the future application (app or excel, language, aquaculture system, end-user)

II. Define work packages and milestones for the implementation of a new fish species in MyFishCheck and document them in writing.
   a. Who does the literature research, when?
   b. Which experts will review the results?

III. When all work packages and milestones are clearly defined, it is beneficial to set a schedule in consultation with the MyFishCheck team to stick to during the implementation process.
   a. Who does the back- and frontend implementation, when?

IV. All work packages and milestones of the implementation process should be clearly communicated to all people involved in the team and be available in writing at any time.
   a. Clarify and document any IP regulations in advance.

Standard **O**perating **P**rocedure **SOP** for implementing a new fish species into MyFishCheck

12th January 2023

1. Defining phase
2. **Data collecting phase**
3. Data management phase
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5. Go-live phase

I. The fish species in question must be subjected to a scientific and comprehensive literature research. Using the templates provided by MyFishCheck in PowerPoint format, an initial overview of the parameters is created. The parameters are in the five modules
   a. farm management
   b. water quality
   c. fish behaviour
   d. fish morphology
   e. fish anatomy

   It is important to understand that you can add additional parameters or omit individual parameters, if needed.

II. Verifiable empirical values may be included within the «data collecting phase». In general, as diverse and different sources as possible should be included in the literature research and data collecting. While focusing on peer-reviewed papers, expert opinions or expertise may be included, particularly if official literature is rare.

Standard **O**perating **P**rocedure **SOP** for implementing a new fish species into MyFishCheck

12th January 2023

1. Defining phase
2. Data collecting phase
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I. During the "data management phase" the MyFishCheck templates should be filled in within the PowerPoint format. It is imperative that the PowerPoint format is retained for the implementation by the MyFishCheck programmer. Within the templates:
   a. references for the literature are given for each parameter under the title "Literature".
   b. comments on the parameters and their relevance should be written under the heading "Remarks".
   c. under "Parameter question" it is noted what exactly this parameter is supposed to clarify.
   d. abbreviations for the prevailing farming system and its localization (IN/OUT) as well as the fish species should be given under "Location, System, Species".
   e. a parameter title is selected under «Parameter»
   f. the intervals of the parameter are listed under «Parameter intervals».
   g. the parameters scores, score weights and parameter weights can be inserted under «PS», «SW», «PW» respectively.

II. Contact the MyFishCheck team if you have any questions about the template.

III. Finally, the fully completed MyFishCheck template in PowerPoint format is sent to the MyFishCheck team for review and backend implementation.

Standard **O**perating **P**rocedure **SOP** for implementing a new fish species into MyFishCheck

12th January 2023

1. Defining phase
2. Data collecting phase
3. Data management phase
4. **Testing phase**
5. Go-live phase

I. After the MyFishCheck team has checked and implemented the templates, access to MyFishCheck is available as an Excel file and as a mobile phone app and is tested on site during the "testing phase".

II. It is recommended to carry out a comprehensive testing with the MyFishCheck app with several people involved.

III. Ensure a complete feedback report to the MyFishCheck team and organise potential development iterations. If errors are discovered or further adjustments to the implementation are needed, the templates in PowerPoint should be adjusted and the MyFishCheck team contacted accordingly.

IV. After successful testing, a final version of all documents is filed and made available according to the IP regulations specified.

Standard **O**perating **P**rocedure **SOP** for implementing a new fish species into MyFishCheck

12th January 2023

1. • Defining phase
2. • Data collecting phase
3. • Data management phase
4. • Testing phase
5. • **Go-live phase**

I. When the backend is fully implemented and testing is completed successfully, the frontend implementation is organised by the MyFishCheck team.

II. After full implementation the new app version can go live.

III. For questions, in case of uncertainties or for support you can contact the MyFishCheck team:
   a. info@myaquaculturefarm.ch
   b. Linda.Tschirren@zhaw.ch