fishes

Review

A Global Assessment of Welfare in Farmed Fishes: The FishEthoBase

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Received: 15 February 2019; Accepted: 7 May 2019; Published: 16 May 2019

Abstract: Fish welfare is an essential issue that needs to be tackled by the aquaculture industry. In order to address it, studies have been limited to a small number of species and the information is generally scattered. In order to have a consistent overview of the welfare of farmed fishes, we present the FishEthoBase, an open-access database that ultimately aims to provide information on the welfare of all fish species currently farmed worldwide. Presently with 41 species, this database is directed to all stakeholders in the field and targets not only to bridge the gaps between them but also to provide scientific information to improve the welfare of fish. The current text explains the database and presents an analysis of the welfare scores of 41 species, suggesting that (i) the general welfare state of farmed fishes is poor, (ii) there is some potential for improvement and (iii) this potential is related to research on species' needs, but (iv) there are many remaining knowledge gaps and (v) current fish farming technologies do not seem to fully address welfare issues. The existence of a framework, such as the FishEthoBase, is proposed as fundamental to the design of strategies that improve the welfare of farmed fish.

Keywords: fish welfare; ethology; FishEthoBase; risk analysis; welfare scores; welfare criteria; framework

1. Introduction

Aquaculture is presently the main source of sea food products for human consumption, with approximately 80 million tonnes of harvested fish in 2016 [1]. However, unlike the relatively low number of terrestrial species farmed for food (26 in total), the fish production relies on 362 species [2–4]. This is an astonishing number that fluctuates as new taxa are added each year while others are abandoned [2–4], although it is worth noting that the 20 most common species account for 84.2% of total fish production [5]. In addition, and again in contrast with the amount of information on the biology of terrestrial farm animals, there are severe knowledge gaps regarding many (if not most) farmed aquatic species. The knowledge that does exist is focused primarily on production traits rather than welfare. In fact, research has pushed the physiological limits of many fish species in growth, fertility and size, as a consequence of (or resulting in) highly artificial conditions [6]. This creates an obvious issue regarding welfare: Fish are sentient beings [7–9] and each species has evolved for millennia in natural contexts, developing adaptations, behaviours and coping mechanisms which are relevant for those contexts [10]. The artificial conditions of captivity, particularly in industrial aquaculture, pose a whole new category of stimuli, for which the animals are seldom equipped to deal with: Space restraints, unnatural aggregations, barren environments, handling and other frequent artificial stressors, etc. [11]. Artificial selection may not necessarily be an answer to the issue, because (1) the domestication of fish is very recent and (2) selected or 'domesticated' strains may be far from their welfare optima as a consequence of their domestication processes [3].

Natural behaviour is pivotal for the welfare assessment of captive animals. Behaviour is the first and foremost indicator of the biological state of an animal, and behavioural observations are the best tool to understand not only the physiological state of the individual but also its mental state [3,12–14]. Therefore, the knowledge on the ethology of farmed fish species is a conditio sine qua non for the correct evaluation of their welfare. This evaluation must rely on a clear operational definition of welfare and on robust indicators that are able to measure unambiguously the variables they are assumed to be measuring. Optimal welfare indicators should take into account not only the health of the fish (i.e., a function-based approach to welfare) [15] but also reflect the animals' emotional state (i.e., a feelings-based approach) [16] as well as their natural needs (i.e., a nature-based approach) [11,17]. In addition, assessing cognitive biases [18] and positive affective states [19] is now an important tool to improve the welfare of farmed fish. A suite of operational welfare indicators has been developed extensively for salmon, for example [20,21], while a broader framework of behavioural indicators is also available for fishes in general [14].

A definition of welfare that complies with the criteria previously addressed is: "The state of the individual as it copes with the environment" [22,23]. This definition of welfare has several implications:

> *"1) Welfare is a characteristic of an animal, not something that is given to it; 2) Welfare will vary from very poor to very good, i.e., the individual may be in a poor state at one end of the welfare continuum or in a good state at the other, 3) Welfare can be measured objectively and independently of moral considerations; 4) Measures of failure to cope and measures of how difficult it is for an animal to cope both give information about how poor the welfare is; 5) Knowledge of the preferences of an animal often gives valuable information about what conditions are likely to result in good welfare, but direct measurements of the state of the animal must also be used in attempts to assess welfare and improve it; and 6) Animals may use a variety of methods when trying to cope. There are several consequences of failure to cope, so any one of a variety of measures can indicate that welfare is poor, and the fact that one measure, such as growth, is normal does not mean that welfare is good".*
>
> ([22], page 4168)

It is well known that domesticated land animals still display behaviours that reflect adaptation to their evolutionary environments, despite not being necessary in their rearing contexts [24]. Considering that this phenomenon occurs in species that have been under domestication for millennia, it is more than likely to occur also in fish, whose domestication process is far more recent: Centuries in the case of carp, tilapia and trout, or decades as in the case of most of the cultured fish recently [3]. The behavioural patterns of fishes observed in the wild are, therefore, the gold standard to assess their welfare state. Although phenotypic plasticity may surely play a role in the adaptation of a fish species to artificial rearing [25–28] it is nevertheless imperative to understand the ethology or natural behavioural repertoire of farmed animals in order to evaluate their welfare conditions and implement measures to mitigate the effects of life in captivity.

In this paper we will:

- Describe in detail the FishEthoBase project, an open-access database on fish ethology and welfare.
- Use these data to assess the general welfare state of farmed fishes presently and use the scoring scheme in the database (FishEthoScore) to provide an outlook on the potential of fish species to be farmed in good welfare.

2. The FishEthoBase Project

The database aims to provide the basis for the global assessment of the welfare of farmed fish. The public portal www.fishethobase.net is a platform where the scientific knowledge regarding the ethology of ultimately all farmed aquatic species is reviewed, scrutinised, organised and summarised in order to answer relevant questions concerning welfare. The database, therefore, aims to bridge the gap between the scientific community and the aquaculture industry. The data are organised into two main approaches:

(1) Full profiles, divided into Findings, where an extensive review on the biology of the species in the wild and in captivity is assessed through bibliographical reviews. Recommendations, where proposals for rearing in captivity under good welfare conditions are made on the basis of the review, and a Summary where this knowledge is condensed.
(2) Short profiles, where a rapid assessment of the welfare state of each species is performed through literature-based answers to 10 core criteria, pointing at main problems and possible solutions, and providing the base for the numerical assessment of welfare–the FishEthoScore.

The fundamental idea underlying the FishEthoBase is to devise a series of criteria that can be applied to all farmed species, and therefore create a framework that allows the comparison of species in terms of welfare. By asking the same questions about all species, not only can we compare their welfare state, but also assess and rank their potential to be farmed in good welfare conditions. The details of the methodology and rationale are explained below.

2.1. Full Profiles—Findings

The findings section on the database aims to be a systematic and exhaustive literature review of the essential knowledge on the behavioural biology of each farmed species, with the purpose of understanding in depth how the farming conditions affect the fish. All entries are referenced, identified in the text with a number, and the reference list is detailed by citing order at the bottom of each species' profile. The following criteria, containing detailed sub-criteria, are addressed:

- Ethograms
- Distribution
- Natural co-existence
- Substrate and/or shelter
- Food, foraging, hunting, feeding
- Photoperiod
- Water parameters
- Swimming
- Growth
- Reproduction
- Senses
- Communication
- Social behaviour
- Cognitive abilities
- Personality, coping styles
- Emotion-like states
- Self-concept, self-recognition
- Reactions to husbandry

2.2. Full Profiles—Recommendations

The data presented in the findings section is used to create a series of recommendations, which provide essential tools for the humane rearing of the species reviewed. These are not meant to be equivalent in detail to a farming manual but rather present how systems should be designed to accommodate the fishes' needs. For example, it is likely that the recommendations discourage from certain practices that studies have indicated to be detrimental to welfare or suggest alternative methods that have been demonstrated to improve the welfare state.

2.3. Summary

All the previous data is condensed in a shorter and less technical text to deliver the main information to a broader audience.

2.4. Short Profiles

The Short Profiles Section of the database aims to be a sharp assessment tool of the general welfare state of a farmed species. To achieve this, a set of 10 core criteria was chosen to portray the variables in fish farming most likely to affect the welfare of fish (see Section 2.4.1 for a description of why and how the criteria were selected). Each criterion is divided into the general life stages of the animal, which generally correspond to rearing stages in the farming environment: Eggs, larvae (hatchery), juveniles (nursery), adults (grow-out) and spawners (broodstock). The entries for each life stage then refer to the knowledge in nature (i.e., in the "Wild") and under aquaculture conditions (i.e., in "Farm"), ideally discriminating the various farming methods when literature is available. For each criterion, the existing knowledge on the biology in the wild is, therefore, overlapped with the existing knowledge on farming conditions, which will implicitly allow drawing conclusions on the welfare conditions of the species regarding that criterion. Furthermore, this overlap is the basis for the scoring of the FishEthoScore, an index that summarises the likelihood of good welfare under common rearing conditions, the potential for rearing under good welfare in high-standard conditions and the certainty of our findings (explained in detail in Section 2.4.2).

The formalisation logic of the entries is summarised in Figure 1.

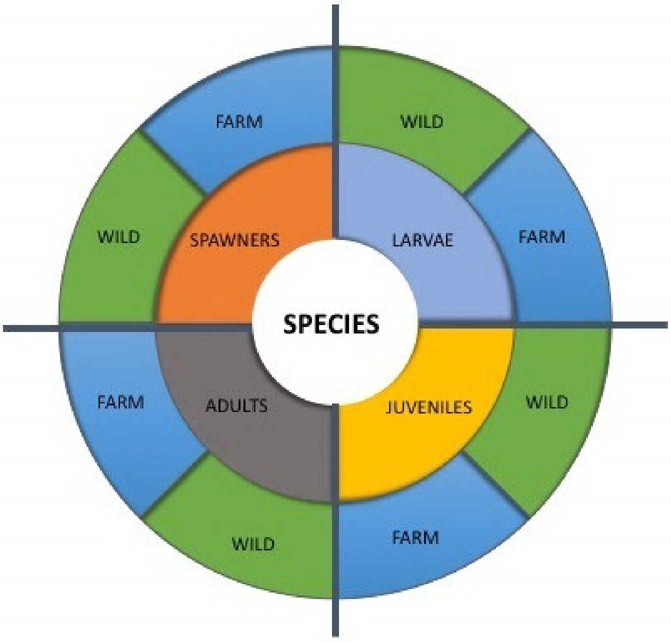

Figure 1. Logic and organization of the entries in the Short Profiles. Each species is divided into four main life stages (larvae, juveniles, adults and spawners), corresponding to four production stages (hatchery, nursery, grow-out and broodstock). For each of these, the entries provide information from the wild and under farming conditions (see text for details).

All entries in the database are referenced, identified in the text with a number, and the reference list is detailed by citing order at the bottom of each species' profile. When there is no reliable information on any of the sections described above, a standard sentence 'no data found yet' is entered. When findings are contradictory or insufficient, the entry becomes 'further research needed . . . ' to highlight the existence of knowledge gaps.

2.4.1. Selected Criteria for the Short Profiles

The basic rationale for the short profiles is that the catalogue of questions, or criteria, designed to achieve a rapid evaluation of the welfare state of a farmed species should be as short and sharp as possible. We arbitrarily set the cut off line at 10 critical questions, which should (i) depict the major limitations imposed to the lives of fish under farming conditions and, therefore, directly impact their welfare (ii) be able to be applied to all farmed species. These criteria were designed to take into account not only the multidimensional nature of welfare (mental, physiological and natural [29–31]) but also common conceptual guidelines towards animal welfare in practice—namely the five freedoms [29] and the allostatic model [32,33].

In general, the constraints imposed on fish in any farming method are: Restricted space, manipulation and handling, low complexity of the environment, unnatural aggregation of individuals, artificial feed and feeding regime, and slaughter. The selection of the 10 core criteria, therefore, reflects these impositions (Table 1).

Table 1. Description and rationale of criteria used in the short profiles of the FishEthoBase www.fishethobase.net.

Criterion	Type of Constraint	Possible Effects
1. Home range	Spatial	Disrupted swimming behaviour, impaired movement.
2. Depth range	Spatial	Disrupted swimming behaviour, impaired movement.
3. Migration and habitat change	Spatial	Disrupted swimming behaviour, migration drivers not met (feeding, reproduction, habitat choice, etc.).
4. Free reproduction	Physiological, Behavioural	Impaired mating, courting and spawning behaviours, inbreeding, disrupted sexual selection.
5. Aggregation	Social	Impaired communication and swimming patterns, disrupted social networks, territoriality and shoaling configurations, increased overall cost of high social stress.
6. Aggression	Behavioural, social	Increased fighting and injuries, increased overall cost of high social stress.
7. Substrate and shelter	Environmental, ecological	Altered swimming and/or feeding patterns, reduced opportunities for escape, disrupted flight response, increased overall cost of high social stress.
8. Handling	Physiological, Mental	Infection, injury, anxiety, chronic stress, pain, death.
9. Malformations	Physiological	Impaired mobility, feeding, breathing or other aspects of biology.
10. Slaughter	Death	Extreme pain and suffering.

1. Home Range

By definition, farming fish implies holding individuals in a confined area. The dimensions of such horizontal space restriction vary greatly according to the rearing method, the species and the life stage. In some species and life stages these dimensions may potentially match the natural behaviour of the species (e.g., *C. idella* [34], *O. niloticus* [35,36], *S. aurata* [37,38], *C. gariepinus* [39,40]) while in most cases this does not happen and may, therefore, have a negative effect in fish welfare [41].

2. Depth Range

Similarly to the home range, all farming methods require a depth limitation to avoid the escape of fish. In species living in shallow waters, their natural depth range is matched by some farming methods and solutions. However, there is a huge variation in physical and environmental components depending on the depth of the water column [42,43]. Therefore, limiting the natural vertical movements to depths that are feasible for aquaculture systems may directly impair fish welfare. Furthermore, shallow depths may also interfere with welfare through higher exposure to anthropogenic disturbances [44,45], inadequate exposure to light [44] and ultraviolet radiation [46] or forced contact with surface-dwelling disease agents [47].

3. Migration and Habitat Change

Spatial restraints become especially relevant if they impede migration. The negative effects may be mitigated if farmers provide the animals with the resources they are migrating for, e.g., access to mates, target feed or season-appropriate environmental conditions (for example, *C. gariepinus* moving shallower to spawn which could be simulated by draining water [48], *S. salar* moving from freshwater to the sea at smolt stage [49] may be mimicked by transferring the fish to saltwater). In most cases, however, the welfare of species that perform seasonal movements due to spawning, feeding, environmental or other needs may be strongly affected by captivity because often the motivation to migrate is not yet known, or whether providing the resource negates the desire or need to migrate, or even it is impossible to meet under farming conditions [50].

4. Reproduction

In broodstocks, natural reproduction (i.e., without any type of direct manipulation of the animals) is generally accepted as a sign of good welfare: Spontaneous spawning only occurs if the stressors in the captive environment are not strong enough to inhibit the neuroendocrine reproductive pathways [51]. Therefore, the investment in breeding will only be worthwhile for an individual if conditions are suitable. In many broodstocks, however, reproduction is induced through hormonal stimulation and/or spawning is achieved through stripping or other invasive procedures to streamline production [51]. The welfare of the fish may thus be impaired directly by the procedure and indirectly by the associated handling [52] (see also 8. Handling below).

5. Aggregation

To streamline fish farming, the animals need not only to be confined but also to be aggregated in order to minimise spatial requirements and maximise catch per effort. There are many ways to calculate and define the number of fish per unit of space or volume and time, and the concept itself is complex [52,53]. However, the artificial manipulation of inter-individual distances during extended periods of the lifetime of fishes may surely represent a major impairment of their welfare: Aggregation below biologically relevant densities may be an issue in naturally shoaling or schooling species, while high density in solitary species may cause stress, infection, behavioural disorders or mortality [11]. The responses to rearing densities are nevertheless specific to species and life stage [11,52,54].

6. Aggression

The rearing of aggressive species, or the facilitation of aggressive behaviour in farmed species due to confinement, density or farming method, is not advisable for obvious reasons: Injuries, stress, decrease in production and overall hindering of welfare [11]. For example, chronic subordination in hierarchical species (that are often prevalent in the aquaculture industry, such as salmonids and sparids) leads to serious welfare problems in low-ranking individuals [55–59]. Aggressive interactions may also indirectly impair other aspects in fish life, such as nutrition [60], growth [61] or the immune system [62] for example.

7. Substrate and Shelter Needs

Fish farming hygiene standards and routine activities (cleaning, feeding, grading, harvesting, etc.) generally require simple or barren environments: For example, raceways and tanks are advised to have smooth surfaces to ensure water flow and prevent the accumulation of detritus [63,64]. Sea cages are usually barren for the same reason. While pelagic species might not need substrate or shelter, benthic species rely on substrate features for shelter, nesting or other uses that are an essential part of their natural environment (e.g., *S. aurata*, *O. niloticus* or *S. solea)*. When such species are farmed under standard methods, their natural requirements are not met, and their welfare may be impaired. This also applies to auxiliary species, such as lumpfish used to de-lice salmon in sea cages [65]: This species is naturally benthic throughout most of its life [66] and would require a substrate to meet its natural needs.

8. Handling

Manipulation and handling are the most direct acute and chronic stressors that occur in aquaculture. These including routine actions, such as cleaning and culling, regular events, such as grading, sexing, transport, vaccination or other treatments, and high impact procedures, such as crowding, harvesting and slaughtering. The effects of manipulation and handling on welfare are well documented: Physical, physiological and mental stress, injury, infection and death [11,50,52]. These routines are the most invasive actions imposed on farmed aquatic animals and the ones that most highly disturb and impair their welfare [67]. However, these aspects may readily be improved, as they depend solely on engineering solutions.

9. Malformations

Malformations can and do occur naturally in fishes. However, many abnormalities found in farmed species arise, are evoked by or occur in higher frequency due to the farming conditions themselves: Collisions due to spatial restrictions or early stage incorrect rearing temperatures may be responsible for skeletal deformities, common diseases or absence of optimum water quality may cause morphological problems, nutritional or feeding deficiencies or may easily delay or impair growth and cause cataracts, for example [68,69]. While taking into account that the lack of predation and lower competition found in the aquaculture environment allow longer survival of deformed fish (at least theoretically), these individuals have, nevertheless, their welfare impaired by deformations prompted by human action [70].

10. Stunning and Slaughter

Humane slaughter is a key feature for the good welfare of farmed fish. However, most farmed species are slaughtered commercially through asphyxia in ice [71], despite the fact that there are presently many solutions that ensure either immediate and painless death or render the fish unconscious through effective stunning [71–78] These solutions, however, are not applied as consistently as expected, which results in a vast majority of aquaculture production being slaughtered in poor conditions that impose excruciating and unnecessary suffering to individuals. In addition, humane slaughtering of fish results in better overall product quality [79].

Supplemental Criterion (A): Domestication Level

The artificial selection processes that led to domestication in terrestrial animals are in effect in fish. Theoretically, the selection of strains that show better adaptation to the rearing environment would possibly benefit the welfare of the animals. However (1) the concept of 'better adaptation' is often anthropomorphic and based on production indicators, not welfare [3] and (2) The artificial selection of fish is very recent, and despite its intensity, it is not clear whether we can truly refer to fish as domesticated [3,4]. Therefore, although it is undeniable that human-induced selection occurs, its effect on welfare is often ambiguous and scoring domestication level as positive or negative in welfare terms becomes equivocal (see Section 2.4.2).

Supplemental Criterion (B): Forage Fish in the Feed

The final question of the short profiles deals not only with the welfare of the focal species but with the ecological and welfare influence of forage fisheries on harvested animals. The undeniable impact of this activity should not be taken lightly [80] but the welfare effects of fishmeal and fish oil replacement with alternative sources are not yet fully determined: There are reports of health and development problems of farmed individuals using fish meal and fish oil replacements [81]. Therefore, scoring forage fishery and replacement with sustainable sources as positive or negative in welfare terms is confusing (see Section 2.4.2).

The data compiled, summarised and critically reviewed in these criteria is the backbone of the database. It should allow the user to make an informed evaluation of the current and potential welfare state of the species and show where there are knowledge gaps that deserve further research, regardless of the additional scoring we provide and that is described in the following section.

2.4.2. Scoring Framework: The FishEthoScores

In addition to providing data on each of the criteria, the information is also summarised in welfare scores: The FishEthoScores are extracted from the entries, and the scoring framework is based on a common risk analysis background [82] to condense the existing information and determine:

- The **Likelihood** that the fish experience good welfare under the lowest standard farming conditions found in the literature regarding that specific criterion. The possible scores are Low, High, Unclear or No Findings;
- The **Potential** for the species to experience good welfare in the highest standard rearing conditions regarding that specific criterion (or the expected improvements in the near future). The possible scores are Low, Medium, High, Unclear or No Findings.
- The **Certainty** of our assessment of the criterion, i.e., a measurement of the general quality, quantity and clarity of the data available for the species. The possible scores are Low, Medium, High or No Findings.

The questions, answers and the scoring framework are logically designed so that affirmative responses have a positive valence, while negative responses have a negative valence (Table 2).

Table 2. Questions regarding the 10 selected criteria for the Short Profiles in the FishEthoBase www.fishethoase.net.

Criterion	Question(s)	Possible Answers
1	Are minimal farming conditions likely to provide the home range of the species?	Likelihood is **High**. Likelihood is **Low**. Data are **Unclear**.
	Is there potential for improvement?	Potential is **High**. Potential is Medium. Potential is Low. Data are **Unclear**. There are **No findings** to support scoring.
	How certain are these findings?	Certainty is **High**. Certainty is **Medium**. Certainty is **Low**. There are **No findings** to support scoring.

Table 2. *Cont.*

Criterion	Question(s)	Possible Answers
2	Are minimal farming conditions likely to provide the depth range of the species?	Likelihood is **High**. Likelihood is **Low**. Data are **Unclear**.
	Is there potential for improvement?	Potential is **High**. Potential is Medium. Potential is **Low**. Data are **Unclear**. There are **No findings** to support scoring.
	How certain are these findings?	Certainty is **High**. Certainty is **Medium**. Certainty is **Low**. There are **No findings** to support scoring.
3	Are minimal farming conditions compatible with the migrating or habitat-changing behaviour of the species?	Likelihood is **High**. Likelihood is **Low**. Data are **Unclear**.
	Is there potential for improvement?	Potential is **High**. Potential is **Medium**. Potential is **Low**. Data are **Unclear**. There are **No findings** to support scoring.
	How certain are these findings?	Certainty is **High**. Certainty is **Medium**. Certainty is **Low**. There are **No findings** to support scoring.
4	Is the species likely to reproduce in captivity without manipulation?	Likelihood is **High**. Likelihood is **Low**. Data are **Unclear**.
	Is there potential to allow for it under farming conditions?	Potential is **High**. Potential is **Medium**. Potential is **Low**. Data are **Unclear**. There are **No findings** to support scoring.
	How certain are these findings?	Certainty is **High**. Certainty is **Medium**. Certainty is **Low**. There are **No findings** to support scoring.
5	Is the aggregation imposed by minimal farming conditions likely to be compatible with the natural behaviour of the species?	Likelihood is **High**. Likelihood is **Low**. Data are **Unclear**.
	Is there potential to allow for it under farming conditions?	Potential is **High**. Potential is **Medium**. Potential is **Low**. Data are **Unclear**. There are **No findings** to support scoring.
	How certain are these findings?	Certainty is **High**. Certainty is **Medium**. Certainty is **Low**. There are **No findings** to support scoring.

Table 2. *Cont.*

Criterion	Question(s)	Possible Answers
6	Is the species likely to be non-aggressive and non-territorial?	Likelihood is **High**. Likelihood is **Low**. Data are **Unclear**.
	Is there potential for improvement?	Potential is **High**. Potential is **Medium**. Potential is **Low**. Data are **Unclear**. There are **No findings** to support scoring.
	How certain are these findings?	Certainty is **High**. Certainty is **Medium**. Certainty is **Low**. There are **No findings** to support scoring.
7	Are minimal farming conditions likely to match the natural substrate and shelter needs of the species?	Likelihood is **High**. Likelihood is **Low**. Data are **Unclear**.
	Is there potential for improvement?	Potential is High. Potential is **Medium**. Potential is **Low**. Data are **Unclear**. There are **No findings** to support scoring.
	How certain are these findings?	Certainty is **High**. Certainty is **Medium**. Certainty is **Low**. There are **No findings** to support scoring.
8	Are minimal farming conditions (handling, confinement etc.) likely not to stress the individuals of the species?	Likelihood is **High**. Likelihood is **Low**. Data are **Unclear**.
	Is there potential for improvement?	Potential is **High**. Potential is **Medium**. Potential is **Low**. Data are **Unclear**. There are **No findings** to support scoring.
	How certain are these findings?	Certainty is **High**. Certainty is **Medium**. Certainty is **Low**. There are **No findings** to support scoring.
9	Are malformations of this species likely to be rare under farming conditions?	Likelihood is **High**. Likelihood is **Low**. Data are **Unclear**.
	Is there potential for improvement?	Potential is **High**. Potential is **Medium**. Potential is **Low**. Data are **Unclear**. There are **No findings** to support scoring.
	How certain are these findings?	Certainty is **High**. Certainty is **Medium**. Certainty is **Low**. There are **No findings** to support scoring.

Table 2. *Cont.*

Criterion	Question(s)	Possible Answers
10	Is a humane slaughter protocol likely to be applied under minimal farming conditions?	Likelihood is **High**. Likelihood is **Low**. Data are **Unclear**.
	Is there potential for improvement?	Potential is **High**. Potential is **Medium**. Potential is **Low**. Data are **Unclear**. There are **No findings** to support scoring.
	How certain are these findings?	Certainty is **High**. Certainty is **Medium**. Certainty is **Low**. There are **No findings** to support scoring.

The FishEthoScores for each species follow a conservative strategy and are determined through the simple sum of the high scores in each dimension:

Likelihood FishEthoScore: The sum of 'High' scores throughout the criteria, varies between 0 and 10.
Potential FishEthoScore: The sum of 'High' scores throughout the criteria, varies between 0 and 10.
Certainty FishEthoScore: The sum of 'High' scores throughout the criteria, varies between 0 and 10.

The FishEthoScores are, therefore, a conservative quantitative summary of a qualitative assessment. The strategy to exclusively use the sum of 'High' scores and avoid attributing intermediate values to other possible scores ("Medium", "Low", "Unclear" or "No findings") is deliberate. In that sense, the FishEthoScores may be a simplification (which any index inherently is) but we opt to lose detailed information so that the calculation of the score is consistent and straightforward. In any case, the scoring information is available both in all the text entries and summarised in a table the top section of each short profile.

Taken together, the three FishEthoScores aim to be representative of the overall welfare state for each species under farming conditions, i.e., high FishEthoScores represent good welfare whereas low FishEthoScores represent poor welfare.

The dimensions (Likelihood, Potential and Certainty) are independent of each other, therefore allowing comparisons and rankings among species and among criteria. The FishEthoBase is highly dynamic, is continuously growing and ever-evolving as new species are added and new papers are published. For this analysis, we will use the data publicly available on 31 October 2018 (41 species).

3. Assessment of Welfare in Farmed Fish Species

A complete table of all the species analysed with their corresponding FishEthoScores is provided as Supplementary Material.

Using the FishEthoScores, we analysed the meaningful correlations between them. We used the scores on Likelihood, Potential, Certainty and Improvement Capacity (measured as Potential minus Likelihood as a proxy to gauge how far a species is from its best possible welfare conditions) in a Spearman correlation matrix, in order to answer questions, such as (but not limited to):

- Are farmed fish species experiencing good welfare?
- Is there potential for farmed species to experience good welfare?
- Are fish species far from their best possible welfare conditions? Does the existing knowledge influence the current or prospective welfare state of farmed fish?
- Are fish species which currently experience better welfare the ones who show the greatest potential to be farmed in best conditions?

All tests were two-tailed with α = 0.05. Correlations and significance tests were performed using Microsoft Excel.

Regarding the low-standard farming conditions, the average *Likelihood* score is 0.44 ± 0.02 (mean ± SE) (in a maximum of 10). The maximum value found is four in the Kingfish *Seriola lalandi* followed by three in the Nile tilapia *Oreochromis niloticus.*

Considering the high-standard practices found in the literature, the average *Potential* is 1.37 ± 0.04 (in a maximum of 10), with a maximum of eight in the Nile tilapia followed by six in the African catfish *Clarias gariepinus.*

The current knowledge regarding the 10 criteria is also sub-optimal, as *Certainty* has an average of 1.93 ± 0.04 with a maximum of six in the Nile tilapia followed by five in African catfish and in the European sea bass *Dicentrarchus labrax.*

There seems to be little *Improvement Capacity*, as on average the species are 0.93 points away (where zero is the complete fulfillment) to achieve their full welfare potential. The case where there is more capacity to improve is the African catfish, where six points separate the best from the worst conditions.

Conversely, the domestication levels of farmed fish according to [83] are high, with an average of 3.90 ± 0.02 (in a maximum of five) and many cases where species are fully domesticated (i.e., there are already selective breeding programs, focused on different traits, such as growth, yield, flesh quality, etc.) [83,84].

The correlation matrix between these variables is summarised in Table 3. We found significant correlations between Likelihood and Potential. The latter is also correlated with Certainty and Improvement Capacity. No other significant correlations are found.

Table 3. Correlation matrix for the selected variables. Values are Spearman ρ. Significant correlations are marked with *.

	Likelihood	Potential	Certainty	Domestication	Improvement Capacity
Likelihood	1				
Potential	0.60 *	1			
Certainty	0.21	0.56 *	1		
Domestication	0.02	0.11	0.14	1	
Improvement Capacity	0.08	0.80 *	0.49	0.18	1

4. Discussion

The FishEthoBase is the first (and, to our knowledge, the only) exhaustive database concerning the welfare of farmed fishes. Despite the limitations inherent to any database, it nevertheless provides a broad overview of the variability of farmed fish species, their specificities concerning welfare and the current knowledge regarding the main welfare aspects that may be affected by farming practices. However, perhaps even more importantly, it provides an overview of the empty spaces: Not only does it point out the research gaps but also the mismatch between scientific advances and industry practices. In many cases this mismatch is due to practices implemented in fish farms being ahead of what is known and published in academia. In others, it is the other way around. Therefore, one of the major aims of FishEthoBase is to help clear the opacity between the two fields and favour the communication between them.

According to the review of the literature, the low-standard farming conditions generally fail to respond to the basic welfare needs of farmed fish. Although slightly better, the high-standard conditions found in the literature nevertheless also fail to meet the basic welfare requirements of these species. Even considering that the approach of the FishEthoBase is very broad and conservative, that the industry has advances which take time to reach the literature (and vice-versa) and that any kind scoring is limited to some degree by subjective bias, the scenario seems to be bleak. Specifically concerning the Likelihood that a species is presently being reared in good welfare according to the lowest standards found in the literature, no species reaches a positive mark (i.e., >5). Regarding the

Potential to be reared in good welfare, only two species (Nile tilapia and African catfish) out of the 41 have a positive mark. A possible conclusion is that, according to the criteria and evaluation detailed above and based on the scientific literature available, these are the two species whose biology seems to be most appropriate to cope with captive conditions, which nevertheless need to be of the highest standard. All the other 39 in the database fail to pass this test, which may be due to the incapacity of rearing systems to meet the welfare needs of the species at some point of its life cycle, or to the biology of the species not being suitable for farming, regardless of human appetites and industry inclinations. The notion that some species cope better with farming conditions than others is not new (e.g., see [85]) and it is based on the long and extremely diverse evolutionary history of fish. It should, therefore, be possible to exploit biological traits of fish species in order to achieve viable production while maintaining good welfare and imposing minimal stress. On the other hand, some species may not be suitable to cope with aquaculture (at least using the present methods or in a foreseeable future), and therefore, their farming should be either revised or discouraged. Domestication or selection of phenotypes ("strains") that present better indicators could be an answer. However, it should be noted that the process of domestication is very recent in fish [4,83] and may introduce variability in the fish response to rearing that should be dealt with caution [3,85].

The positive correlation between Likelihood and Potential indicates that the species who seem to cope better with its current farming conditions are the ones who have the greatest potential to experience welfare in high-standard farms. It also means that the potential of a species to be reared under good welfare is dependent on its current welfare state. This may be related to the biology of these species, but it is possible that better solutions are available (or under development) for these species because both academia and the industry realise that good welfare 'pays off' also in terms of production: If fish experiencing good welfare perform well, further improving their welfare will also improve their performance.

One of the key results from this analysis is the strong correlation between Certainty and Potential. This suggests that knowledge and research are key to improve the conditions of farmed fish, which contributes to better production results [86,87]. Welfare has also been shown to be a driver when consumers choose their animal products in some markets [88,89], while in others this driver is present only in some segments of the population [90]. The knowledge provided by the FishEthoBase may, therefore, not only be a key to identify research gaps in the welfare of farmed species, but also paves the way for consumer information and future welfare certification schemes that are science-based, reliable, efficient and verifiable.

One result that may be a cause for concern is the very low Improvement Capacity. This means that, in general, there is not much that can be done to improve the welfare of farmed species. This can be explained either because of the species' biology, specific welfare needs throughout the life cycle or at certain stages, or limitations in farming methods and technology. Rather not surprisingly, the Improvement Capacity is also related to the Potential, which is self-explanatory.

Interestingly, the high domestication level in farmed fishes does not seem to improve their welfare. This is probably because the recent domestication process of fish has been focusing more on production traits than welfare [3], which is also suggested by the low scores on Certainty. In fact, many species have a large body of research regarding feeding, growth or spawning (e.g., tilapia, salmon, trout, sea bream, sea bass) yet the knowledge on welfare traits and indicators is rudimentary, as demonstrated by the low Certainty score. In Europe, recent efforts have been undertaken to address these knowledge gaps. One example is the COST action 'Welfare of fish in European aquaculture', that produced a high number of reports for these species, e.g., [71,73,74,76,77]. Another example is the growing number of papers on welfare of Atlantic salmon [20,54,91–94], that highlights the rising importance of welfare for the farming of this species. Nonetheless, it is still a drop in an empty ocean of knowledge (or lack thereof) for the remaining more than 300 species farmed worldwide.

5. Conclusions

In this discussion, we analysed the general trends from the FishEthoScores, and concluded that (i) the general welfare state of farmed fish species is bad, (ii) there is some potential for fish to be reared in better welfare conditions, (iii) this potential is generally related to research on species' needs but (iv) there is much to be done in order to fill in the knowledge gaps and (v) current or prospective fish farming technologies do not seem to allow much improvement. However, we believe we have barely scratched the surface for data exploration. The database is open access and the concept behind it is that the users should explore the portal and its contents to its fullest potential, either in generic terms as we have done here, or in a species-specific manner. Nevertheless, we reiterate the idea that the real essence and value are the data compiled, summarised and critically reviewed for each species. The FishEthoScore is crude yet useful quantification tool to assess the general welfare state of the species—though prone to subjective interpretation. The knowledge underpinning the scores, however, is indeed objective and should allow the user to make an informed evaluation of welfare state of the species, identify the knowledge gaps and eventually design solutions to improve the lives of farmed fish. As new knowledge is gained, the team behind the FishEthoBase continues to update the database. Furthermore, the concept of this project is to provide an open platform for researchers, industry members and other stakeholders to share their expertise and critically examine the data available.

Supplementary Materials: The following are available online at http://www.mdpi.com/2410-3888/4/2/30/s1, Table S1: FishEthoScores for 41 farmed fish species available in the open access database FishEthoBase www.fishethobase.net.

Author Contributions: Database concept: B.H.S., J.V., J.L.S., P.A.-L., M.F.C.; formal analysis of data, J.L.S.; investigation, B.H.S., J.V., J.L.S., P.A.-L., M.F.C.; data curation, B.H.S., J.V., J.L.S., P.A.-L., M.F.C.; writing—original draft preparation, J.L.S.; review and editing, B.H.S., J.V., J.L.S., P.A.-L., M.F.C.; project administration, B.H.S., J.L.S., J.V.; funding acquisition, B.H.S., J.L.S.

Funding: This work was funded by Open Philanthropy Project (San Francisco, USA), Swiss Federal Food Safety and Veterinary Office (Bern, Switzerland), Stiftung Dreiklang (Basel, Switzerland), Haldimann-Stiftung (Aarau, Switzerland) and other private donations. This study received Portuguese national funds from FCT—Foundation for Science and Technology through project UID/Multi/04326/2019.

Acknowledgments: We acknowledge many contributions from stakeholders that continuously allow the growing and improvement of the database.

Conflicts of Interest: The authors declare no conflict of interest.

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