animals

MDPI

Supplementary Material

MyFishCheck: A Model to Assess Fish Welfare in Aquaculture

Supplementary S2: Parameter Table

Literature review for the 80 welfare parameters to define the intervals. Allocation of the parameter scores (PS) and the score weights (SW) according to the number of intervals. Expert survey for the 80 welfare parameters to define their relative importance resulting in the parameter weights.

	Literature	Remarks	Parameter question	Location System Species	Parameter	Parameter intervals	PS	SW	PW	SWE PWE
Farm management	FAWC 1996 [1]; North et al. 2008 [2]; Segner et al. 2019 [3]	Good education, training, and experience of the fish farmers secure fish welfare. In Switzerland, the legal minimum for fish farms is for at least one person to have the "FBA Aquakultur" course.	What is the highest training of the personnel in charge?	In / Out RAS / FTS RT / PP	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 [1]; Timmons et al. 2010 [4]; Bregnballe 2015 [5]	Regular controls allow for early detection and prevention of problems that potentially can impair fish welfare. The appropriate interval for controls varies for different parts of the system, different farm systems, different life stages of the fish etc.	How are the farm's systems checked?	In / Out RAS / FTS RT / PP	Daily check	0: Daily check with appropriate controls	0	1	5	
						1: Daily check	-0.5	3		
						2: System is checked insufficiently	-1	5		
	North et al. 2008 [2]; Jentoft et al. 2005 [6]; Noble et al. 2020 [7]	A reduction of disturbances to only the unavoidable level in farming assists good fish welfare.	Are the fish exposed to external disturbances?	In / Out RAS / FTS RT / PP	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		
	FAWC 1996 [1]; North et al. 2008 [2]; Noble et al. 2020 [7]	Predation from birds or mammals can impact welfare through attacks and injuries.	Are the fish protected from predators?	Out RAS / FTS RT / PP	Predator protection	0: Completely protected from predators	0	1	4	
						1: Partially protected from predators	-0.5	3		
						2: Not protected	-1	5		
	North et al. 2008 [2]; Bregnballe 2015 [5]; Klontz 1991 [8]	Proper storage, cleaning and handling of all sorts of material assists a secure functioning of the system and a working hygiene protocol and with this secures fish welfare.	Is the farm and the used material kept clean?	In / Out RAS / FTS RT / PP	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		
	North et al. 2008 [2]; Swiss Federal Council 2016 [9]	Documentation of medication and disinfection measures assists the tracking of health and welfare problems and the effects of the measures. In Switzerland, the documentation of any medication is mandatory.	Are chemical measures documented?	In / Out RAS / FTS RT / PP	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		
		Written and easily accessible specifics about the system's target value and corresponding action plans if those values are not met help secure the fish health and welfare.	Are target values and action plans available?	In / Out RAS / FTS RT / PP	Target value sheet	0: Target value document and action plan are accessible	0	1	4	0 1.7
						1: Target value document and an action plan are known, but not documented	-0.5	3		
						2: There are no target values or specific action plan applied	-1	5		
	North et al. 2008 [2]; Segner et al. 2019 [3]; Bregnballe 2015 [5]	Written and easily accessible emergency plans help secure the fish health and welfare. Appropriate emergency plans are system specific.	Is an emergency plan available?	In / Out RAS / FTS RT / PP	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		
	Bregnballe 2015 [5]; Noble et al. 2020 [7]; Meyer 1991 [10]	Written and easily accessible hygiene concepts help secure the fish health and welfare. Appropriate hygiene concepts are system specific.	Is a hygiene concept available?	In / Out RAS / FTS RT / PP	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		
	Swiss Federal Council 2008 [11]; Ellis et al. 2012 [12]; Kleingeld et al. 2016 [13]	Documentation of mortalities assists the tracking of health and welfare problems and the effects of the measures. In Switzerland, the documentation of any mortality is mandatory.	Are mortalities documented?	In / Out RAS / FTS RT / PP	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 [8]; Kleingeld et al. 2016 [13]; Woynarovich et al. 2011 [14]	Documentation of biomass and stocking density assists the appropriate feeding, good system maintenance and correct timing of husbandry procedures, all of which help to secure fish welfare. The FCR (feed convertion ratio) is an indicator for fish health and farm management.	Are biomass, stocking density and FCR documented?	In / Out RAS / FTS RT / PP	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		
	Zienert & Heidrich 2005 [15]; Zakęś et al. 2004 [16]; Baekelandt et al. 2018 [17]	Sorting the shoal helps to maintain a homogeneously sized group, but the procedure also inflicts stress. An appropriate sorting procedure and interval help maintain fish welfare and health in the long-term.	Is the sorting interval appropriate?	In / Out RAS / FTS RT / PP	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		
	Ellis et al. 2012 [12]; Robb 2008 [18]; Lines & Spence 2012 [19]	Humane slaughtering includes short crowding times, effective and lasting stunning, and fast killing. In Switzerland, fish must not show any signs of consciousness (reflexes) between stunning and death.	Is the slaughter process humane?	In / Out RAS / FTS RT / PP	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	Ellis et al. 2002 [20]; North et al. 2006 [21]; Turnbull et al. 2008 [22]; Skov et al. 2011 [23]	Stocking density is correlated with other welfare parameters such as water quality and group behaviour. In Switzerland, the density is regulated to a maximum of 80 kg/m^3 for salmonids and 100 kg/m^3 for cyprinids. Depending on the system too low densities may favour territoriality and/or aggression in the shoal.	What is the current stocking density?	In / Out RAS / FTS RT	Stocking density	0: 0–40 kg/m^3	0	1	3	0 1.7
						1: 40–60 kg/m^3	-0.5	3		
						2: 60–80 kg/m^3	-1	5		
	Zienert & Heidrich 2005 [15]; Steenfeldt et al. 2010 [24]; Dalsgaard et al. 2013 [25]			In / Out RAS / FTS PP		0: 0–30 kg/m^3	0	1		
						1: 30–50 kg/m^3	-0.5	3		
						2: 50–80 kg/m^3	-1	5		
	McCarthy et al. 1992 [26]; Moutou et al. 1998 [27]; Wang et al. 2009 [28]; López-Olmeda et al. 2012 [29]	Feeding rate (kg feed / kg biomass) and interval (amount of feed per feeding and numbers of feedings per day) influence growth, health and social behaviour.	The current feeding interval and rate secures how many points?	In / Out RAS / FTS RT / PP	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		
	Baekelandt et al. 2018 [17]; Geay & Kestemont 2015 [30]; Antony Jesu Prabhu et al. 2015 [31]	Feed type (reproduction, rearing, salmonids, percids etc.) and pellet size of the feed are appropriate to the fish species and life stage.	Is the feed type and size appropriate?	In / Out RAS / FTS RT / PP	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 [32]; Karakatsouli et al. 2007 [33]; Mizusawa et al. 2007 [34]	Ambient light is a relevant external factor for biological processes and therefore fish health and welfare. Appropriate light conditions vary with fish species and fish life stage.	Is the ambient light appropriate?	In RAS / FTS RT	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		
	Zienert & Heidrich 2005 [15]; Baekelandt et al. 2018 [17]; Feiner & Höök 2015 [35]			In RAS / FTS PP	Ambient light[3]	0: Light intensity and phases are adjusted	0	1		
						1: Light intensity or light phases are adjusted	-0.5	3		
						2: Neither light intensity nor light phases are adjusted	-1	5		
	Noble et al. 2005 [32]; Karakatsouli et al. 2007 [33]; Mizusawa et al. 2007 [34]	Light conditions in the tanks influence social and feeding behaviour. Appropriate light conditions vary with fish species, fish life stage and farm system.	Is the light in the husbandry tanks appropriate?	In RAS / FTS RT	Tank light[4]	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 RT	Tank light[5]	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		
	Geay & Kestemont 2015 [30]; Feiner & Höök 2015 [35]; Luchiari et al. 2006 [36]			In RAS / FTS PP	Tank light[6]	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		
				Out RAS / FTS PP	Tank light[7]	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 behaviour (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: the (room) lighting allows safe working of the personnel and a visual inspection of the fish
- Light intensity: the room lighting is soft, the fish behave calmly
- Light phases: any transitions from light/dark phases are long/gentle, fish always remain calm

4 - Light intensity: fish are protected from excessive light intensity (either by shading or sufficient water depth or weak ambient lighting)
- 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

5 - Light intensity: fish are protected from excessive 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

6 - 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

7 - 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

	Literature	Remarks	Parameter question	Location System Species	Parameter	Parameter intervals	PS	SW	PW	SWE PWE
Water quality	Woynarovich et al. 2011 [14]; Schurmann et al. 1991 [37]; Bear et al. 2007 [38]; Lewis et al. 2010 [39]; Beakes et al. 2014 [40]; Janhunen et al. 2016 [41]	Water temperature affects biological processes and is a key aspect of water quality. Preferences and tolerances are fish species and life stage specific, and intervals need to be adapted accordingly. In Switzerland, the upper limit for the temperature of the system water is 22 °C for salmonids and 30 °C for cyprinids.	Temperature of the system water in [°C]	In / Out RAS / FTS RT	Temperature	Optimum: [10–16]	0	1	4	1.7
						Within target range: [6–10) ∪ (16–18]	-0.33	2.33		
						Within the tolerance range: [4–6) ∪ (18–22]	-0.66	3.66		
						Outside the tolerance range: [0–4) ∪ (22–35]	-1	5		
	Willemsen 1978 [42]; Frisk et al. 2012 [43], 2013 [44]; Swirplies et al. 2019 [45]			In / Out RAS / FTS PP		Optimum: [20–25]	0	1		
						Within target range: [13–20) ∪ (25–28]	-0.33	2.33		
						Within the tolerance range: [8–13) ∪ (28–30]	-0.66	3.66		
						Outside the tolerance range: [0–8) ∪ (30–40]	-1	5		
	Zienert & Heidrich 2005 [15]; Glencross 2009 [46]; Labbé et al. 2014 [47]; Swiss Federal Council 2016 [9]	Oxygen is needed for biological processes and is a key aspect of water quality. While preferences are similar for most farmed fish species, tolerance ranges are fish species and life stage specific and intervals can be adapted accordingly. In Switzerland, the lower limit for oxygen in the system water is 5 mg/l for salmonids and 3.5 mg/l for cyprinids.	Dissolved oxygen (O_2) in the system water in [mg/l]	In / Out RAS / FTS RT / PP	Oxygen	Optimum: [8–10]	0	1	5	1.7
						Within target range: [7–8) ∪ (10–13]	-0.33	2.33		
						Within the tolerance range: [6–7) ∪ (13–15]	-0.66	3.66		
						Outside the tolerance range: [2–6) ∪ (15–30]	-1	5		
	Klontz 1991 [8]; Boyd & Tucker 1998 [48]; Baekelandt et al. 2018 [17]		Dissolved oxygen (O_2) in the system water in [% saturation]	In / Out RAS / FTS RT / PP	Oxygen saturation	Optimum: [80–120]	0	1	5	1.7
						Within target range: [70–80) ∪ (120–140]	-0.33	2.33		
						Within tolerance range: [60–70) ∪ (140–160]	-0.66	3.66		
						Outside the tolerance range: [20–60) ∪ (160–300]	-1	5		
	Wicks et al. 2002 [49]; Capkin et al. 2009 [50]; Steinberg et al. 2018a [51]	Ammonium is fish toxic and a relevant water quality parameter in RAS. Little data for pikeperch is available. Since ammonium is the main factor for ammonia levels and toxicity of ammonia is similar in trout and pikeperch, 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 RT / PP	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		
	Zienert & Heidrich 2005 [15]; Calamari et al. 1981 [52]; Randall & Tsui 2002 [53]; Schram et al. 2014 [54]	Ammonia is highly fish toxic and a relevant water quality parameter in RAS. Ammonia levels are mostly calculated from TAN and pH values. In Switzerland, the upper limit for ammonia in the system water is 0.01 mg/l for salmonids and 0.02 mg/l for cyprinids.	Ammonia (NH_3-N) of the system water in [mg/l]	In / Out RAS RT / PP	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		
	Russo et al. 1974 [55]; Williams & Eddy 1986 [56]; Kroupova et al. 2008 [57]	Nitrite is highly fish toxic and a relevant water quality parameter in RAS. Pikeperch might be up to 10 times more tolerant to nitrite than salmonids, however conclusive evidence is still missing. 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 RT / PP	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		
	Labbé et al. 2014 [47]; Müller-Belecke et al. 2013 [58]; Steinberg et al. 2018b [59]	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 RT / PP	Nitrate	Optimum: [0–50]	0	1	2.5	
						Within target range: (50–75]	-0.33	2.33		
						Within tolerance range: (75–150]	-0.66	3.66		
						Outside tolerance range: (150–500]	-1	5		

	Literature	Remarks	Parameter question	Location System Species	Parameter	Parameter intervals	PS	SW	PW	SWE PWE
Water quality	Wedemeyer 1996 [60]; Altinok et al. 2006 [61]; Boyd et al. 2016 [62]	Carbonate hardness affects the stability of the water quality and biological processes of the fish. °fH and °dH are convertible into mg/l of $CaCO_3$.	Carbonate hardness of the system water in $CaCO_3$ [mg/l]	In / Out RAS / FTS RT / PP	Carbonate hardness	Optimum: [40–150]	0	1	3	
						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		
	Steinberg et al. 2018a [51]; Wedemeyer 1996 [60]; Becke et al. 2018 [63]	High TSS values are indicators of low water quality and impact the function and health of the gills.	TSS of the system water in [mg/l]	In / Out RAS / FTS RT / PP	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		
	Klontz 1991 [8]; Zienert & Heidrich 2005 [15]; Altinok et al. 2006 [61]	pH affects biological processes of the fish and the biofilter, and is a key aspect of water quality. In Switzerland, the legal allowed range for the pH of the system water is 5.5–9.	pH of the system water	In / Out RAS / FTS RT / PP	pH	Optimum: [7–7.5]	0	1	4	
						Within target range: [6.5–7) ∪ (7.5–8]	-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		
	Brown et al. 2001 [64]; Altinok & Grizzle 2003 [65]; Scott et al. 2008 [66]; Xiong et al. 2019 [67]	Preferences/tolerances for salinity vary considerably among fish species, hence the parameter should be added to the model when assessing fish adapted to salt or brackish water. For freshwater species salinity can be measured via the conductivity. Other ions affect conductivity as well (e.g. nitrate) and limit upper conductivity levels for welfare before the salinity itself impairs welfare.	Conductivity of the system water in [µS/cm]	In / Out RAS / FTS RT / PP	Conductivity	Optimum: [500–1000]	0	1	2	1.7 1.7
						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		
	Wedemeyer 1996 [60]; Good et al. 2010 [68]; Steinberg et al. 2017 [69]	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 RT / PP	Carbon dioxide	Optimum: [0–5]	0	1	3.5	
						Within target range: (5–20]	-0.33	2.33		
						Within tolerance range: (20–30]	-0.66	3.66		
						Outside the tolerance range: (30–100]	-1	5		
	Wedemeyer 1996 [60]; Weitkamp et al. 1980 [70]; Bohl 1997 [71]	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 RT / PP	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 [72]; Lauff & Wood 1996 [73]; Larsen et al. 2012 [74]; Huntingford & Kadri 2013 [75]	Water velocity affects fish welfare (e.g. physiological exercise, group behaviour) as well as system functioning (e.g. tank self-cleaning, biofilter efficiency). Optimal and tolerance values are fish species and life stage as well as system specific and need to be adapted accordingly.	Water velocity in the fish tank in [body lengths/sec]	In / Out RAS / FTS RT / PP	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		

	Literature	Remarks	Parameter question	Location System Species	Parameter	Parameter intervals	PS	SW	PW	SWE PWE
Fish group behaviour	Noble et al. 2020 [7]; Ellis et al. 2002 [20]; Ashley 2007 [76]; Martins et al. 2012 [77]; Magnhagen 2015 [78]	Dominant (e.g. fin or opercula spreading, approaching) and aggressive (e.g. biting, bumping) behaviours are costly for both the dominant and the submissive individual. They cause stress and potentially injuries and hence are a threat to the welfare of the fish.	Is aggressive behaviour detectable when observing the fish group?	In / Out RAS / FTS RT / PP	Aggression	0: No fish shows dominance or aggression	0	1	3.5	
						1: Individual fish show dominance behaviour	-0.2	1.8		
						2: Some fish show dominance behaviour	-0.4	2.6		
						3: Individual fish show aggression behaviour	-0.6	3.4		
						4: Some fish show aggressive behaviour	-0.8	4.2		
						5: Many fish are either dominant or aggressive	-1	5		
		Territoriality can cause aggression and if key areas (inlet, feeder, shelter, shading) are monopolized it may further impair health and welfare by preventing certain fish the access to these recourses.	Is territorial behaviour detectable when observing the fish group?	In / Out RAS / FTS RT / PP	Territoriality	0: No fish shows territorial behaviour	0	1	3	
						1: Individual fish show territorial behaviour	-0.2	1.8		
						2: Some fish show territorial behaviour	-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 [2]; Kleingeld et al. 2016 [13]; Martins et al. 2012 [77]	Jumping out of the water and/or scratching the body on surfaces (often visible as "flashing" when the brighter ventral side of the fish shortly shows) are signs of discomfort mostly cause by pathogens. The behaviours are therefore indicators of reduced health and welfare.	Is scratching detectable when observing the fish group?	In / Out RAS / FTS RT / PP	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		1.7
	Noble et al. 2020 [7]; Kleingeld et al. 2016 [13]; Martins et al. 2012 [77]	Apathy i.e. the lack of behaviours (e.g. feeding or swimming), especially after external stimuli (e.g. fleeing) are a sing of impaired health and welfare.	Is apathic behaviour detectable when observing the fish group?	In / Out RAS / FTS RT / PP	Apathy	0: No fish show signs of apathy	0	1	5	1.7
						1: Individual fish show apathetic swimming behaviour, react normally to stimulation	-0.2	1.8		
						2: Some fish show apathetic swimming behaviour, react normally to stimulation	-0.4	2.6		
						3: Individual fish show apathetic swimming behaviour, do not react to stimulation	-0.6	3.4		
						4: Some fish show apathetic swimming behaviour, do not respond to stimulation	-0.8	4.2		
						5: Many fish show apathetic swimming behaviour, do not respond to stimulation	-1	5		
		Fish separating themselves from the shoal is caused by social of physiological stress and is therefore an indication of impaired health and/or welfare.	Is isolating behaviour detectable when observing the fish group?	In / Out RAS / FTS RT / PP	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 pattern (e.g. laying on the bottom or drifting at the surface) can be indicators of social (submissive/avoiding behaviour) or physiological (buoyancy problems, pain) problems. This parameter is fish species specific as different fish have a different use of the water column and hence the parameter and its intervals should be adapted if needed.	Where in the water column are the fish?	In / Out RAS / FTS RT / PP	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	North et al. 2008 [2]; Noble et al. 2020 [7]; Noga 2010 [79]	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.	Is air gulping detectable when observing the fish group?	In / Out RAS / FTS RT / PP	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		
		Chronically altered ventilation (i.e. increased/decreased rates or magnitude of the opercula movements) are signs of chronic stress and health impairments. The effects of acute stress (feeding time, external disturbance) have to be considered when defining deviations for "normal" ventilation behaviour.	Is the ventilation rate normal?	In / Out RAS / FTS RT / PP	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		
	Kleingeld et al. 2016 [13]; Martins et al. 2012 [77]; Davis 2010 [80]	Fleeing behaviour is normal for all most fish species. A prolonged or missing reaction to external stimuli is a sign of impaired health and welfare.	Is the fleeing behaviour normal?	In / Out RAS / FTS RT / PP	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 behaviour	-0.2	1.8		
						2: Some fish show an increased and/or prolonged fleeing behaviour	-0.4	2.6		
						3: Individual fish show no or constant fleeing behaviour	-0.6	3.4		
						4: Some fish show no or constant fleeing behaviour	-0.8	4.2		
						5: Many fish show no or constant fleeing behaviour	-1	5		
		An abnormal position of the fins can be an indicator of social of physiological stress. The normal position of fins may be species specific and any assessment of abnormal behaviours should be adapted accordingly.	Is the fin position normal?	In / Out RAS / FTS RT / PP	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		
	Davis 2010 [80]; Lee 1893 [81]; MacIntyre et al. 2008 [82]	Fish should be able to constantly uphold an upright body position and have proper orientation within the water column. Struggle or failure to do this indicate physiological problems.	Do the fish have good balance?	In / Out RAS / FTS RT / PP	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		
	North et al. 2008 [2]; Segner et al. 2019 [3]; Noga 2010 [79]; Ferguson 2006 [83]	Changes in body colouration (e.g. pale or darkened) can indicate social or physiological stress. The particular body colouration is fish species and life stage specific and can be subject to seasonal changes. These aspects have to be considered when defining deviations for "normal" body colouration.	Are the fish coloured normally?	In / Out RAS / FTS RT / PP	Body colour	0: All the fish show a normal body colouration	0	1	3	
						1: Single fish have temporarily a conspicuously bright or dark colouration	-0.2	1.8		
						2: Some fish have temporarily a conspicuously bright or dark colouration	-0.4	2.6		
						3: Individual fish have constantly striking a bright or dark colouration	-0.6	3.4		
						4: Some fish constantly have a noticeable light or dark colour	-0.8	4.2		
						5: Many fish constantly have a noticeable light or dark colour	-1	5		
	North et al. 2008 [2] ; Noble et al. 2020 [7]; Martins et al. 2012 [77]	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.	Is the feeding behaviour expressed normally?	In / Out RAS / FTS RT / PP	Feeding	0: All fish show normal feeding behaviour	0	1	3	
						1: Individual fish show a very hungry, hectic eating behaviour	-0.2	1.8		
						2: Some fish show a very hungry, hectic eating behaviour	-0.4	2.6		
						3: Individual fish show a starved, aggressive eating behaviour	-0.6	3.4		
						4: Some fish show a starved, aggressive eating behaviour	-0.8	4.2		
						5: Many fish show a starved, aggressive eating behaviour	-1	5		

	Literature	Remarks	Parameter question	Location System Species	Parameter	Parameter intervals	PS	SW	PW	SWE PWE
Fish group behaviour	North et al. 2008 [2]; Kestemont et al. 2007 [84]; Rodger & Phelps 2015 [85]; Policar et al. 2016 [86]	Deformations may inflict pain and/or restrict movement, breathing, and feeding and therefore impair fish health and welfare. Information about how many fish are affected, and when and how fast the deformations appeared can assist the identification of the causes and potential measures for improvement.	How many fish have jaw deformations?	In / Out RAS / FTS RT / PP	Jaw deformations	0: No fish has injuries/deformations of the jaw/snout	0	1	3	
						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 RT / PP	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 RT / PP	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 [87]; Noble et al. 2012 [88]	Injuries inflict pain and/or restrict movement, breathing, and feeding and therefore impair fish health and welfare. Information about how many fish are affected, and when and how fast the injuries appeared can assist the identification of the causes and potential measures for improvement.	How many fish have eye injuries?	In / Out RAS / FTS RT / PP	Eye injuries	0: No fish has eye injuries/deformations	0	1	3	1.7
						1: Individual fish have slight injuries/deformations to the eyes	-0.2	1.8		1.7
						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 RT / PP	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 RT / PP	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 [10]; Kleingeld et al. 2016 [13]; Noga 2010 [79]	Infections of the body and fins with fungi or moulds are a sign of impaired health and welfare. Information about how many fish and which body parts are affected, and when and how fast the infection appeared can assist the identification of the causes and potential measures for improvement.	How many fish have fungal or mould infections?	In / Out RAS / FTS RT / PP	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		

	Literature	Remarks	Parameter question	Location System Species	Parameter	Parameter intervals	PS	SW	PW	SWE PWE
Fish external appearance	North et al. 2008 [2]; Noble et al. 2020 [7]; Kleingeld et al. 2016 [13]; Noga 2010 [79]; Ferguson 2006 [83]; Rodger & Phelps 2015 [85]; Pettersen et al. 2014 [89]	The eye is a major organ and any damage to it can affect fish health and welfare. Causes and effects of different eye damages vary depending on the nature of the damage. Hence cataracts, bleedings, injuries and exophthalmia are each separate parameters. Their distinction assists the assessment of the impairment of health and welfare and helps identifying the causes and potential measures for improvement. While the inflicted pain or discomfort might be equal amongst fish, the effects of impaired vision are species specific i.e. more impairment is expected in visual predators and highly social species.	Does the fish have clouding of the eye lens?	In / Out RAS / FTS RT / PP	Cataract	0: Both eyes are clear	0	1	3	
						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 RT / PP	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 RT / PP	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		
	Policar et al. 2016 [86]; Bosakowski & Wagner 1994 [90]; Hoyle et al. 2007 [91]	The fins are key for movement and communication and any damage to them can affect fish health and welfare. Causes and effects of different fin damages vary depending on the nature (e.g. rotting, erosion, abrasion, bites) and the location (i.e. pectoral, ventral, anal, caudal, dorsal) of the damage. Hence the fins are each separate parameters. The distinction assists the assessment of the impairment of health and welfare and helps identifying the causes and potential measures for improvement.	Does the fish have damages or deformations of the pectoral fins?	In / Out RAS / FTS RT / PP	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 RT / PP	Ventral fins	0: Undamaged fins	0	1	2	1.7
						1: One-sided/both-sided: indications of scar tissue or small/active fin damage	-0.33	2.33		1.7
						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 RT / PP	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 RT / PP	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 RT / PP	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	Barnes et al. 2014 [92]; Dekic et al. 2016 [93]; Zahedi et al. 2019 [94]	As a ratio of weight and length the body condition factor is a health and welfare indicator for fish that reacts in the mid- and long-term to suboptimal husbandry conditions. As the value is strongly influenced by the basic body shape, the optimal and tolerance values are fish species and life stage specific and need to be adapted accordingly.	Fulton's condition factor K [bodyweight/ standardlength^3 x 100]	In / Out RAS / FTS RT	Body condition factor	0: 1–1.3	0	1	3	
						1: 0.8–1.5	-0.33	2.33		
						2: > 1.5	-0.66	3.66		
						3: < 0.8	-1	5		
	Steinberg et al. 2017 [69]; Molnar et al. 2006 [95]; Zakęś et al. 2012 [96]			In / Out RAS / FTS PP		0: 0.9–1.1	0	1		
						1: 0.7–1.3	-0.33	2.33		
						2: > 1.3	-0.66	3.66		
						3: < 0.7	-1	5		
	Noble et al. 2020 [7]; Ashley 2007 [76]; Rodger & Phelps 2015 [85]; Noble et al. 2012 [88]; Branson & Turnbull 2008 [97]	Deformations of the spine may inflict pain and/or restrict movement and therefore affect feeding, behaviour, and health and welfare.	Does the fish have spinal deformations?	In / Out RAS / FTS RT / PP	Spinal deformation	0: No indication	0	1	3	
						1: Indication of deformation	-0.33	2.33		
						2: Clear deformation	-0.66	3.66		
						3: Strong deformation	-1	5		
		Deformations of the jaws may inflict pain and/or restrict feeding and breathing and therefore affect health and welfare.	Does the fish have deformations of the lower or upper jaw?	In / Out RAS / FTS RT / PP	Jaw deformation	0: No indication	0	1	3	
						1: Indication of deformation	-0.33	2.33		
						2: Clear deformation	-0.66	3.66		
						3: Strong deformation	-1	5		
		Injuries of the mouth and the jaws inflict pain and/or restrict feeding and breathing and therefore affect health and welfare.	Does the fish have an injury on the mouth?	In / Out RAS / FTS RT / PP	Mouth injury	0: No indication	0	1	3	
						1: A few small injuries	-0.33	2.33		
						2: Several small injuries	-0.66	3.66		
						3: One or more large/deep injuries	-1	5		
	North et al. 2008 [2]; Noga 2010 [79]; Ferguson 2006 [83]	External pathogens (parasites, fungi, moulds, bacteria) generally impair fish health and welfare. Assessing the parasite load in the mucus in a semi-quantitative way helps assessing the health, tracking counter measures and detecting problems early.	Are parasites visible in a mucus swop under a 40-100 fold magnification?	In / Out RAS / FTS RT / PP	Mucus pathogens	0: No parasites detectable	0	1	4	1.7
						1: A few parasites	-0.33	2.33		1.7
						2: Considerable parasite load	-0.66	3.66		
						3: Heavy parasite load	-1	5		
	North et al. 2008 [2]; Kleingeld et al. 2016 [13]; Ferguson 2006 [83]; Rodger & Phelps 2015 [85]; Noble et al. 2012 [88]	The skin is a major barrier between the fish and its environment and any damage to it can affect fish health and welfare. Causes and effects of different skin damages vary depending on the nature of the damage. Hence alterations, fungal infections, bleedings, injuries and scale loss are each separate parameters. Their distinction assists the assessment of the impairment of health and welfare and helps identifying the causes and potential measures for improvement.	Does the fish have alterations of the skin?	In / Out RAS / FTS RT / PP	Skin alterations	0: No indication	0	1	3.5	
						1: A few small alterations (tumours, swellings, rashes, bleedings)	-0.33	2.33		
						2: Several small alterations (tumours, swellings, rashes, bleedings)	-0.66	3.66		
						3: One or more large alterations (tumours, swellings, rashes, bleedings)	-1	5		
			Does the fish have fungi or moulds on the skin? (fins are excluded)	In / Out RAS / FTS RT / PP	Skin fungus	0: No indication	0	1	4	
						1: A few small areas infected	-0.33	2.33		
						2: Several small areas infected	-0.66	3.66		
						3: One or more large areas infected	-1	5		
			Does the fish have an injury of the skin or loss of scales?	In / Out RAS / FTS RT / PP	Skin injury	0: No indication	0	1	3.5	
						1: A few small injuries or small areas with scale loss	-0.33	2.33		
						2: Several small injuries and/or small areas with scale loss	-0.66	3.66		
						3: One or more large/deep injuries and/or areas with scale loss	-1	5		
	Noble et al. 2020 [7]; Pettersen et al. 2014 [89]; Branson & Turnbull 2008 [97]	Injuries or deformations of the opercula can impose pain and impair breathing and therefore affect health and welfare.	Does the fish have a damage or deformation of the gill cover/opercula?	In / Out RAS / FTS RT / PP	Gill cover	0: Both-sided: undamaged opercula	0	1	2	
						1: One-sided/both-sided: opercula covers min. 2/3 of gill area	-0.33	2.33		
						2: One-sided/both-sided: opercula covers min. 1/3 of gill area	-0.66	3.66		
						3: One-sided/both-sided: opercula covers less than 1/3 of gill area	-1	5		
	North et al. 2008 [2]; Ferguson 2006 [83]; Pettersen et al. 2014 [89]	Injuries or alterations of the gill's primary lamellae may impose pain and can impair breathing and therefore affect health and welfare.	Does the fish have damaged or discoloured gills?	In / Out RAS / FTS RT / PP	Gills	0: Both-sided: undamaged, red gills	0	1	5	
						1: One-sided/both-sided: indications of damaged and/or discoloured gill tissue	-0.33	2.33		
						2: One-sided/both-sided: several small areas of damaged and/or discoloured gill tissue	-0.66	3.66		
						3: One-sided/both-sided: extensive areas of damaged and/or discoloured gill tissue	-1	5		

	Literature	Remarks	Parameter question	Location System Species	Parameter	Parameter intervals	PS	SW	PW	SWE PWE
Fish internal appearance	North et al. 2008 [2]; Ashley 2007 [76]; Noga 2010 [79]; Ferguson 2006 [83]; Pettersen et al. 2014 [89]	Healthy and well functioning organs are key for fish health and welfare. Each organ is a parameter as resulting impairments may be organ specific. The exact nature of the damage of an organ assists the identification of the causes and potential measures for improvement.	How does the fish's heart look like?	In / Out RAS / FTS RT / PP	Heart	0: Inconspicuous	0	1	3	
						1: Slight discolouration	-0.33	2.33		
						2: Discoloured and/or small necrosis and/or small hemorrhages	-0.66	3.66		
						3: Severely discoloured and/or necrosis and/or hemorrhages	-1	5		
			How does the fish's kidney look like?	In / Out RAS / FTS RT / PP	Kidney	0: Inconspicuous	0	1	3.5	
						1: Slight discolouration	-0.33	2.33		
						2: Discoloured and/or slightly granular	-0.66	3.66		
						3: Severely discoloured and/or granular	-1	5		
			How does the fish's spleen look like?	In / Out RAS / FTS RT / PP	Spleen	0: Inconspicuous	0	1	4	
						1: Slight enlargement	-0.33	2.33		
						2: Discoloured and/or slightly enlarged	-0.66	3.66		
						3: Severely discoloured and/or enlarged	-1	5		
			How does the fish's liver look like?	In / Out RAS / FTS RT / PP	Liver	0: Inconspicuous	0	1	4	
						1: Slight discolouration	-0.33	2.33		
						2: discoloured and/or slightly enlarged and/or small necrosis	-0.66	3.66		
						3: Severely discoloured and/or enlarged and/or necrosis	-1	5		
	Noble et al. 2020 [7]; Ferguson 2006 [83]; Pettersen et al. 2014 [89]	Healthy intestines are a sign of and a prerequisite for good nutrition and health. The exact nature of the damage of the organ assists the identification of the causes and potential measures for improvement.	How do the fish's stomach and intestines look like?	In / Out RAS / FTS RT / PP	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 (discolouring, swelling, tumours)	-0.66	3.66		
						3: Inflammation and/or change in tissue (discoloured and/or swollen tissue, tumours, hemorrhages, necrosis) or foreign objects	-1	5		
	Noga 2010 [79]; Ferguson 2006 [83]; Pettersen et al. 2014 [89]	Healthy muscles are key for fish health and welfare. The exact nature of the damage of the tissue assists the identification of the causes and potential measures for improvement.	How does the fish's muscle tissue look like?	In / Out RAS / FTS RT / PP	Muscles	0: Normal	0	1	3	1.7
						1: Single small hemorrhages, small vaccination damage	-0.33	2.33		1.7
						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		
	Noble et al. 2020 [7]; Noga 2010 [79]; Rodger & Phelps 2015 [85]	A healthy body cavity is a sign of and a prerequisite for good health. The exact nature of the damage of the organ assists the identification of the causes and potential measures for improvement.	How does the fish's body cavity look like?	In / Out RAS / FTS RT / PP	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 [2]; Wootton & Smith 2015 [98]; Folkedal et al. 2016 [99]	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. This parameter and its intervals should be adapted depending of the fish species, life stage and purpose of the husbandry.	How far are the ovaries or testes developed?	In / Out RAS / FTS RT / PP	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		
	North et al. 2008 [2]; Noga 2010 [79]; Ferguson 2006 [83]	Injuries or alterations of the gill's secondary lamellae may impose pain and can impair breathing and therefore affect health and welfare.	How do the fish's secondary gill lamellae look like under a 40-100 fold magnification?	In / Out RAS / FTS RT / PP	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 (parasites, fungi, moulds, bacteria) generally impair fish health and welfare. Assessing the parasite load of the gills in a semi-quantitative way helps assessing the health, tracking counter measures and detecting problems early.	Are parasites visible in a gill sample under a 40-100 fold magnification?	In / Out RAS / FTS RT / PP	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		

References

1. FAWC *Report on the Welfare of Farmed Fish*; Farm Animal Welfare Council: Surbiton, **1996.**
2. North, B.P.; Ellis, T.; Bron, J.; Knowles, T.G.; Turnbull, J.F. The use of stakeholder focus groups to identify indicators for the on-farm assessment of trout welfare. In *Fish Welfare*; Branson, E.J., Ed.; Blackwell Publishing Ltd: Oxford, UK, **2008**; pp. 243–267.
3. Segner, H.; Reiser, S.; Ruane, N.; Rösch, R.; Steinhagen, D.; Vehanen, T. *Welfare of Fishes in Aquaculture*; FAO Fisheries and Aquaculture Circular; Food and Agriculture Organization of the United Nations, **2019**; p. 19.
4. Timmons, M.B.; Ebeling, J.M.; Wheaton, F.W.; Summerfelt, S.T.; Vinci, B.J. *Recirculating Aquaculture Systems*; 2nd ed.; Cayuga Aqua Ventures Llc: United States, **2010**.
5. Bregnballe, J. *A Guide to Recirculation Aquaculture*; FAO: Rome, Italy, **2015**.
6. Jentoft, S.; Aastveit, A.H.; Torjesen, P.A.; Andersen, Ø. Effects of Stress on Growth, Cortisol and Glucose Levels in Non-Domesticated Eurasian Perch (*Perca Fluviatilis*) and Domesticated Rainbow Trout (*Oncorhynchus Mykiss*). *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology* **2005**, *141*, 353–358.
7. Noble, C.; Gismervik, K.; Iversen, M.H.; Kolarevic, J.; Nilsson, J.; Stien, L.H.; Turnbull, J.F. *Welfare Indicators for Farmed Rainbow Trout: Tools for Assessing Fish Welfare*; Nofima: Tromsø, Norway, **2020**.
8. Klontz, G.W. *A Manual for Rainbow Trout Production on the Family-Owned Farm*; Thomas Nelson & Sons, **1991**.
9. Swiss Federal Food Safety and Veterinary Office 136.; BLV *Technische Weisung über die amtlichen Kontrollen in der Primärproduktion in Tierhaltungen*; Swiss Federal Council: Berne, Switzerland, **2016**.
10. Meyer, F.P. Aquaculture Disease and Health Management. *Journal of Animal Science* **1991**, *69*, 4201–4208.
11. Swiss Federal Council *Animal Protection Ordinance dated April 23, 2008 (as of July 14, 2020)*; Swiss Federal Council: Berne, Switzerland, **2008**.
12. Ellis, T.; Berrill, I.; Lines, J.; Turnbull, J.F.; Knowles, T.G. Mortality and Fish Welfare. *Fish Physiology and Biochemistry* **2012**, *38*, 189–199.
13. Kleingeld, D.W.; Moritz, J.; Reiser, S.; Steinhagen, D.; Wedekind, H. *Leitfaden „Tierschutzindikatoren"*; Arbeitskreis „Tierschutzindikatoren" des Verbandes Deutscher Fischereiverwaltungsbeamter und Fischereiwissenschaftler e.V.: Rostock, Germany, **2016**; p. 30.
14. Woynarovich, A.; Hoitsy, G.; Moth-Poulsen, T. *Small-Scale Rainbow Trout Farming*; FAO fisheries and aquaculture technical paper; Food and Agriculture Organization of the United Nations: Rome, **2011**.
15. Zienert, S.; Heidrich, S. *Aufzucht von Zandern in der Aquakultur*; Schriften des Instituts für Binnenfischerei e.V. Potsdam-Sacrow; Institut für Binnenfischerei e.V. Potsdam-Sacrow: Potsdam, Germany, **2005**; Vol. 18.
16. Zakęś, Z.; Kowalska, A.; Czerniak, S. Effect of Sorting on Selected Rearing Factors of Pikeperch *Sander Lucioperca* (L.). *Fisheries & Aquatic Life* **2004**, *12*, 71–79.
17. Baekelandt, S.; Redivo, B.; Mandiki, S.N.M.; Bournonville, T.; Houndji, A.; Bernard, B.; El Kertaoui, N.; Schmitz, M.; Fontaine, P.; Gardeur, J.-N.; et al. Multifactorial Analyses Revealed Optimal Aquaculture Modalities Improving Husbandry Fitness without Clear Effect on Stress and Immune Status of Pikeperch *Sander Lucioperca*. *General and Comparative Endocrinology* **2018**, *258*, 194–204.
18. Robb, D.H.F. Welfare of fish at harvest. In *Fish Welfare*; Branson, E.J., Ed.; Blackwell Publishing Ltd: Oxford, UK, **2008**; pp. 217–242.
19. Lines, J.A.; Spence, J. Safeguarding the Welfare of Farmed Fish at Harvest. *Fish Physiology and Biochemistry* **2012**, *38*, 153–162.
20. Ellis, T.; North, B.; Scott, A.P.; Bromage, N.R.; Porter, M.; Gadd, D. The Relationships between Stocking Density and Welfare in Farmed Rainbow Trout. *Journal of Fish Biology* **2002**, *61*, 493–531.
21. North, B.P.; Turnbull, J.F.; Ellis, T.; Porter, M.J.; Migaud, H.; Bron, J.; Bromage, N.R. The Impact of Stocking Density on the Welfare of Rainbow Trout (*Oncorhynchus Mykiss*). *Aquaculture* **2006**, *255*, 466–479.
22. Turnbull, J.F.; North, B.P.; Ellis, T.; Adams, C.E.; Bron, J.; MacIntyre, C.M.; Huntingford, F.A. Stocking density and the welfare of farmed salmonids. In *Fish Welfare*; Branson, E.J., Ed.; Blackwell Publishing Ltd: Oxford, UK, **2008**; pp. 111–120.

23. Skov, P.V.; Larsen, B.K.; Frisk, M.; Jokumsen, A. Effects of Rearing Density and Water Current on the Respiratory Physiology and Haematology in Rainbow Trout, *Oncorhynchus Mykiss* at High Temperature. *Aquaculture* **2011**, *319*, 446–452.
24. Steenfeldt, S.; Vestergaard, M.; Overton, J.L.; Lund, I.; Paulsen, H.; Larsen, V.J.; Henriksen, N.H. *Further development of intensive pikeperch rearing in Denmark*; DTU Aqua, Institut for Akvatiske Ressourcer: Lyngby, Denmark, **2010**; p. 96.
25. Dalsgaard, J.; Lund, I.; Thorarinsdottir, R.; Drengstig, A.; Arvonen, K.; Pedersen, P.B. Farming Different Species in RAS in Nordic Countries: Current Status and Future Perspectives. *Aquacultural Engineering* **2013**, *53*, 2–13.
26. McCarthy, I.D.; Carter, C.G.; Houlihan, D.F. The Effect of Feeding Hierarchy on Individual Variability in Daily Feeding of Rainbow Trout, *Oncorhynchus Mykiss* (Walbaum). *Journal of Fish Biology* **1992**, *41*, 257–263.
27. Moutou, K.A.; McCarthy, I.D.; Houlihan, D.F. The Effect of Ration Level and Social Rank on the Development of Fin Damage in Juvenile Rainbow Trout. *Journal of Fish Biology* **1998**, *52*, 756–770.
28. Wang, N.; Xu, X.; Kestemont, P. Effect of Temperature and Feeding Frequency on Growth Performances, Feed Efficiency and Body Composition of Pikeperch Juveniles (*Sander Lucioperca*). *Aquaculture* **2009**, *289*, 70–73.
29. López-Olmeda, J.F.; Noble, C.; Sánchez-Vázquez, F.J. Does Feeding Time Affect Fish Welfare? *Fish Physiology and Biochemistry* **2012**, *38*, 143–152.
30. Geay, F.; Kestemont, P. Feeding and nutrition of percid fishes during ongrowing stages. In *Biology and Culture of Percid Fishes: Principles and Practices*; Springer: Dordrecht, The Netherlands, **2015**; pp. 587–622.
31. Antony Jesu Prabhu, P.; Kaushik, S.J.; Mariojouls, C.; Surget, A.; Fontagné-Dicharry, S.; Schrama, J.W.; Geurden, I. Comparison of Endogenous Loss and Maintenance Need for Minerals in Rainbow Trout (*Oncorhynchus Mykiss*) Fed Fishmeal or Plant Ingredient-Based Diets. *Fish Physiology and Biochemistry* **2015**, *41*, 243–253.
32. Noble, C.; Mizusawa, K.; Tabata, M. Does Light Intensity Affect Self-Feeding and Food Wastage in Group-Held Rainbow Trout and White-Spotted Charr? *Journal of Fish Biology* **2005**, *66*, 1387–1399.
33. Karakatsouli, N.; Papoutsoglou, S.E.; Pizzonia, G.; Tsatsos, G.; Tsopelakos, A.; Chadio, S.; Kalogiannis, D.; Dalla, C.; Polissidis, A.; Papadopoulou-Daifoti, Z. Effects of Light Spectrum on Growth and Physiological Status of Gilthead Seabream *Sparus Aurata* and Rainbow Trout *Oncorhynchus Mykiss* Reared under Recirculating System Conditions. *Aquacultural Engineering* **2007**, *36*, 302–309.
34. Mizusawa, K.; Noble, C.; Suzuki, K.; Tabata, M. Effect of Light Intensity on Self-Feeding of Rainbow Trout *Oncorhynchus Mykiss* Reared Individually. *Fisheries Science* **2007**, *73*, 1001–1006.
35. Feiner, Z.S.; Höök, T.O. Environmental biology of percid fishes. In *Biology and Culture of Percid Fishes: Principles and Practices*; Kestemont, P., Dabrowski, K., Summerfelt, R.C., Eds.; Springer Netherlands: Dordrecht, The Netherlands, **2015**; pp. 61–100.
36. Luchiari, A.C.; Freire, F.A.D.M.; Koskela, J.; Pirhonen, J. Light Intensity Preference of Juvenile Pikeperch *Sander Lucioperca* (L.). *Aquaculture Research* **2006**, *37*, 1572–1577.
37. Schurmann, H.; Steffensen, J.F.; Lomholt, J.P. The Influence of Hypoxia on the Preferred Temperature of Rainbow Trout *Oncorhynchus Mykiss*. *Journal of Experimental Biology* **1991**, *157*, 75–86.
38. Bear, E.A.; McMahon, T.E.; Zale, A.V. Comparative Thermal Requirements of Westslope Cutthroat Trout and Rainbow Trout: Implications for Species Interactions and Development of Thermal Protection Standards. *Transactions of the American Fisheries Society* **2007**, *136*, 1113–1121.
39. Lewis, J.M.; Hori, T.S.; Rise, M.L.; Walsh, P.J.; Currie, S. Transcriptome Responses to Heat Stress in the Nucleated Red Blood Cells of the Rainbow Trout (*Oncorhynchus Mykiss*). *Physiological Genomics* **2010**, *42*, 361–373.
40. Beakes, M.P.; Sharron, S.; Charish, R.; Moore, J.W.; Satterthwaite, W.H.; Sturm, E.; Wells, B.K.; Sogard, S.M.; Mangel, M. Using Scale Characteristics and Water Temperature to Reconstruct Growth Rates of Juvenile Steelhead *Oncorhynchus Mykiss*. *Journal of Fish Biology* **2014**, *84*, 58–72.

41. Janhunen, M.; Koskela, J.; Ninh, N.H.; Vehviläinen, H.; Koskinen, H.; Nousiainen, A.; Thỏa, N.P. Thermal Sensitivity of Growth Indicates Heritable Variation in 1-Year-Old Rainbow Trout (*Oncorhynchus Mykiss*). *Genetics Selection Evolution* **2016**, *48*, 94.
42. Willemsen, J. Influence of Temperature on Feeding, Growth and Mortality of Pikeperch and Perch. *SIL Proceedings, 1922-2010* **1978**, *20*, 2127–2133.
43. Frisk, M.; Skov, P.V.; Steffensen, J.F. Thermal Optimum for Pikeperch (*Sander Lucioperca*) and the Use of Ventilation Frequency as a Predictor of Metabolic Rate. *Aquaculture* **2012**, *324–325*, 151–157.
44. Frisk, M.; Steffensen, J.F.; Skov, P.V. The Effects of Temperature on Specific Dynamic Action and Ammonia Excretion in Pikeperch (*Sander Lucioperca*). *Aquaculture* **2013**, *404–405*, 65–70.
45. Swirplies, F.; Wuertz, S.; Bassmann, B.; Orban, A.; Schaefer, N.; Brunner, R.M.; Hadlich, F.; Goldammer, T.; Rebl, A. Identification of Molecular Stress Indicators in Pikeperch *Sander Lucioperca* Correlating with Rising Water Temperatures. *Aquaculture* **2019**, *501*, 260–271.
46. Glencross, B.D. Reduced Water Oxygen Levels Affect Maximal Feed Intake, but Not Protein or Energy Utilization Efficiency of Rainbow Trout (*Oncorhynchus Mykiss*). *Aquaculture Nutrition* **2009**, *15*, 1–8.
47. Labbé, L.; Lefèvre, F.; Bugeon, J.; Fostier, A.; Jamin, M.; Gaumé, M. Conception d'un système innovant de production de truites en eau recirculée. *La Revue INRAE Productions Animales* **2014**, *27*, 135–146.
48. Boyd, C.E.; Tucker, C.S. *Pond Aquaculture Water Quality Management*; Kluwer Academic: Boston, USA, **1998**.
49. Wicks, B.J.; Joensen, R.; Tang, Q.; Randall, D.J. Swimming and Ammonia Toxicity in Salmonids: The Effect of Sub Lethal Ammonia Exposure on the Swimming Performance of Coho Salmon and the Acute Toxicity of Ammonia in Swimming and Resting Rainbow Trout. *Aquatic Toxicology* **2002**, *59*, 55–69.
50. Capkin, E.; Birincioglu, S.; Altinok, I. Histopathological Changes in Rainbow Trout (*Oncorhynchus Mykiss*) after Exposure to Sublethal Composite Nitrogen Fertilizers. *Ecotoxicology and Environmental Safety* **2009**, *72*, 1999–2004.
51. Steinberg, K.; Zimmermann, J.; Meyer, S.; Schulz, C. Start-up of Recirculating Aquaculture Systems: How Do Water Exchange Rates Influence Pikeperch (*Sander Lucioperca*) and Water Composition? *Aquacultural Engineering* **2018**, *83*, 151–159.
52. Calamari, D.; Marchetti, R.; Vailati, G. Effects of Long-Term Exposure to Ammonia on the Developmental Stages of Rainbow Trout (*Salmo Gairdneri* Richardson). *Rapports et procès-verbaux des réunions* **1981**, *178*, 81–86.
53. Randall, D.J.; Tsui, T.K.N. Ammonia Toxicity in Fish. *Marine Pollution Bulletin* **2002**, *45*, 17–23.
54. Schram, E.; Roques, J.A.C.; van Kuijk, T.; Abbink, W.; van de Heul, J.; de Vries, P.; Bierman, S.; van de Vis, H.; Flik, G. The Impact of Elevated Water Ammonia and Nitrate Concentrations on Physiology, Growth and Feed Intake of Pikeperch (*Sander Lucioperca*). *Aquaculture* **2014**, *420–421*, 95–104.
55. Russo, R.C.; Smith, C.E.; Thurston, R.V. Acute Toxicity of Nitrite to Rainbow Trout (Salmo Gairdneri). *Journal of the Fisheries Research Board of Canada* **1974**, *31*, 1653–1655.
56. Williams, E.M.; Eddy, F.B. Chloride Uptake in Freshwater Teleosts and Its Relationship to Nitrite Uptake and Toxicity. *Journal of Comparative Physiology B* **1986**, *156*, 867–872.
57. Kroupova, H.; Machova, J.; Piackova, V.; Blahova, J.; Dobsikova, R.; Novotny, L.; Svobodova, Z. Effects of Subchronic Nitrite Exposure on Rainbow Trout (*Oncorhynchus Mykiss*). *Ecotoxicology and Environmental Safety* **2008**, *71*, 813–820.
58. Müller-Belecke, A.; Zienert, S.; Thürmer, C.; Kaufhold, S.; Spranger, U. The "Self Cleaning Inherent Gas Denitrification-Reactor" for Nitrate Elimination in RAS for Pike Perch (*Sander Lucioperca*) Production. *Aquacultural Engineering* **2013**, *57*, 18–23.
59. Steinberg, K.; Zimmermann, J.; Stiller, K.T.; Nwanna, L.; Meyer, S.; Schulz, C. Elevated Nitrate Levels Affect the Energy Metabolism of Pikeperch (*Sander Lucioperca*) in RAS. *Aquaculture* **2018**, *497*, 405–413.
60. Wedemeyer, G. *Physiology of Fish in Intensive Culture Systems*; Springer US: New York, USA, **1996**.

61. Altinok, I.; Capkin, E.; Karahan, S.; Boran, M. Effects of Water Quality and Fish Size on Toxicity of Methiocarb, a Carbamate Pesticide, to Rainbow Trout. *Environmental Toxicology and Pharmacology* **2006**, *22*, 20–26.
62. Boyd, C.E.; Tucker, C.S.; Somridhivej, B. Alkalinity and Hardness: Critical but Elusive Concepts in Aquaculture. *Journal of the World Aquaculture Society* **2016**, *47*, 6–41.
63. Becke, C.; Schumann, M.; Steinhagen, D.; Geist, J.; Brinker, A. Physiological Consequences of Chronic Exposure of Rainbow Trout (*Oncorhynchus Mykiss*) to Suspended Solid Load in Recirculating Aquaculture Systems. *Aquaculture* **2018**, *484*, 228–241.
64. Brown, J.A.; Moore, W.M.; Quabius, E.S. Physiological Effects of Saline Waters on Zander. *Journal of Fish Biology* **2001**, *59*, 1544–1555.
65. Altinok, I.; Grizzle, J.M. Effects of Low Salinities on Oxygen Consumption of Selected Euryhaline and Stenohaline Freshwater Fish. *Journal of the World Aquaculture Society* **2003**, *34*, 113–117.
66. Scott, D.M.; Rabineau, J.; Wilson, R.W.; Hodgson, D.J.; Brown, J.A. Can Pikeperch Colonise New Freshwater Systems via Estuaries? Evidence from Behavioural Salinity Tests. *Marine and Freshwater Research* **2008**, *59*, 694–702.
67. Xiong, Y.; Wang, X.; Dong, S.; Wang, F.; Yang, J.; Zhou, Y. Comparisons of Salinity Adaptation in Terms of Growth, Body Composition, and Energy Budget in Juveniles of Rainbow and Steelhead Trouts (*Oncorhynchus Mykiss*). *Journal of Ocean University of China* **2019**, *18*, 509–518.
68. Good, C.; Davidson, J.; Welsh, C.; Snekvik, K.; Summerfelt, S. The Effects of Carbon Dioxide on Performance and Histopathology of Rainbow Trout *Oncorhynchus Mykiss* in Water Recirculation Aquaculture Systems. *Aquacultural Engineering* **2010**, *42*, 51–56.
69. Steinberg, K.; Zimmermann, J.; Stiller, K.T.; Meyer, S.; Schulz, C. The Effect of Carbon Dioxide on Growth and Energy Metabolism in Pikeperch (*Sander Lucioperca*). *Aquaculture* **2017**, *481*, 162–168.
70. Weitkamp, D.E.; Katz, M.; Way, N. A Review of Dissolved Gas Supersaturation Literature. *Transactions of the American Fisheries Society* **1980**, *109*, 659–702.
71. Bohl, M. Gas bubble disease of fish. *Tierärztliche Praxis* **1997**, *25*, 284–288.
72. Jobling, M.; Baardvik, B.M.; Christiansen, J.S.; Jørgensen, E.H. The Effects of Prolonged Exercise Training on Growth Performance and Production Parameters in Fish. *Aquaculture International* **1993**, *1*, 95–111.
73. Lauff, R.F.; Wood, C.H. Respiratory Gas Exchange, Nitrogenous Waste Excretion, and Fuel Usage during Aerobic Swimming in Juvenile Rainbow Trout. *Journal of Comparative Physiology B* **1996**, *166*, 501–509.
74. Larsen, B.K.; Skov, P.V.; McKenzie, D.J.; Jokumsen, A. The Effects of Stocking Density and Low Level Sustained Exercise on the Energetic Efficiency of Rainbow Trout (*Oncorhynchus Mykiss*) Reared at 19 °C. *Aquaculture* **2012**, *324*, 226–233.
75. Huntingford, F.; Kadri, S. Exercise, stress and welfare. In *Swimming Physiology of Fish: Towards Using Exercise to Farm a Fit Fish in Sustainable Aquaculture*; Palstra, A.P., Planas, J.V., Eds.; Springer: Berlin, Germany, 2013; pp. 161–174.
76. Ashley, P.J. Fish Welfare: Current Issues in Aquaculture. *Applied Animal Behaviour Science* **2007**, *104*, 199–235.
77. Martins, C.I.M.; Galhardo, L.; Noble, C.; Damsgård, B.; Spedicato, M.T.; Zupa, W.; Beauchaud, M.; Kulczykowska, E.; Massabuau, J.-C.; Carter, T.; et al. Behavioural Indicators of Welfare in Farmed Fish. *Fish Physiology and Biochemistry* **2012**, *38*, 17–41.
78. Magnhagen, C. Behaviour of percid fishes in the wild and its relevance for culture. In *Biology and Culture of Percid Fishes: Principles and Practices*; Kestemont, P., Dabrowski, K., Summerfelt, R.C., Eds.; Springer Netherlands: Dordrecht, **2015**; pp. 399–416.
79. Noga, E.J. *Fish Disease: Diagnosis and Treatment*; 2nd edn.; Wiley-Blackwell: Hoboken, USA, **2010**.
80. Davis, M.W. Fish Stress and Mortality Can Be Predicted Using Reflex Impairment. *Fish and Fisheries* **2010**, *11*, 1–11.
81. Lee, F.S. A Study of the Sense of Equilibrium in Fishes. *The Journal of Physiology* **1893**, *15*, 311–348.

82. MacIntyre, C.M.; Ellis, T.; North, B.P.; Turnbull, J.F. The influences of water quality on the welfare of farmed rainbow trout: A review. In *Fish Welfare*; Branson, E.J., Ed.; Blackwell Publishing Ltd: Oxford, UK, **2008**; pp. 150–184.
83. *Systemic Pathology of Fish: A Text and Atlas of Normal Tissues in Teleosts and Their Responses in Disease*; Ferguson, H.W., Ed.; 2. ed., rev.expanded.; Scotian: London, **2006**.
84. Kestemont, P.; Xueliang, X.; Hamza, N.; Maboudou, J.; Imorou Toko, I. Effect of Weaning Age and Diet on Pikeperch Larviculture. *Aquaculture* **2007**, *264*, 197–204.
85. Rodger, H.D.; Phelps, N.B.D. Percid fish health and disease. In *Biology and Culture of Percid Fishes: Principles and Practices*; Kestemont, P., Dabrowski, K., Summerfelt, R.C., Eds.; Springer Netherlands: Dordrecht, **2015**; pp. 799–813.
86. Policar, T.; Blecha, M.; Křišťan, J.; Mráz, J.; Velíšek, J.; Stará, A.; Stejskal, V.; Malinovskyi, O.; Svačina, P.; Samarin, A.M. Comparison of Production Efficiency and Quality of Differently Cultured Pikeperch (*Sander Lucioperca* L.) Juveniles as a Valuable Product for Ongrowing Culture. *Aquaculture International* **2016**, *24*, 1607–1626.
87. Ashley, P.J.; Sneddon, L.U. Pain and fear in fish. In *Fish Welfare*; Branson, E.J., Ed.; Blackwell Publishing Ltd: Oxford, UK, **2008**; pp. 49–77.
88. Noble, C.; Cañon Jones, H.A.; Damsgård, B.; Flood, M.J.; Midling, K.Ø.; Roque, A.; Sæther, B.-S.; Cottee, S.Y. Injuries and Deformities in Fish: Their Potential Impacts upon Aquacultural Production and Welfare. *Fish Physiology and Biochemistry* **2012**, *38*, 61–83.
89. Pettersen, J.M.; Bracke, M.B.M.; Midtlyng, P.J.; Folkedal, O.; Stien, L.H.; Steffenak, H.; Kristiansen, T.S. Salmon Welfare Index Model 2.0: An Extended Model for Overall Welfare Assessment of Caged Atlantic Salmon, Based on a Review of Selected Welfare Indicators and Intended for Fish Health Professionals. *Reviews in Aquaculture* **2014**, *6*, 162–179.
90. Bosakowski, T.; Wagner, E.J. A Survey of Trout Fin Erosion, Water Quality, and Rearing Conditions at State Fish Hatcheries in Utah. *Journal of the World Aquaculture Society* **1994**, *25*, 308–316.
91. Hoyle, I.; Oidtmann, B.; Ellis, T.; Turnbull, J.; North, B.; Nikolaidis, J.; Knowles, T.G. A Validated Macroscopic Key to Assess Fin Damage in Farmed Rainbow Trout (*Oncorhynchus Mykiss*). *Aquaculture* **2007**, *270*, 142–148.
92. Barnes, M.E.; Brown, M.L.; Bruce, T.; Sindelar, S.; Neiger, R. Rainbow Trout Rearing Performance, Intestinal Morphology, and Immune Response after Long-Term Feeding of High Levels of Fermented Soybean Meal. *North American Journal of Aquaculture* **2014**, *76*, 333–345.
93. Dekic, R.; Savic, N.; Manojlovic, M.; Golub, D.; Pavlicevic, J. Condition Factor and Organosomatic Indices of Rainbow Trout (*Onchorhynchus Mykiss*, Wal.) from Different Brood Stock. *Biotechnology in Animal Husbandry* **2016**, *32*, 229–237.
94. Zahedi, S.; Akbarzadeh, A.; Mehrzad, J.; Noori, A.; Harsij, M. Effect of Stocking Density on Growth Performance, Plasma Biochemistry and Muscle Gene Expression in Rainbow Trout (*Oncorhynchus Mykiss*). *Aquaculture* **2019**, *498*, 271–278.
95. Molnar, T.; Szabo, A.; Szabo, G.; Szabo, C.; Hancz, C. Effect of Different Dietary Fat Content and Fat Type on the Growth and Body Composition of Intensively Reared Pikeperch *Sander Lucioperca* (L.). *Aquaculture Nutrition* **2006**, *12*, 173–182.
96. Zakęś, Z.; Szczepkowski, M.; Jankowska, B.; Kowalska, A.; Demska-Zakęś, K. Slaughter Yield and Growth Performance Indexes of Pikeperch (*Sander Lucioperca* (L.)) Selects Reared in Recirculating Aquaculture Systems at Suboptimal Temperatures. *Archives of Polish Fisheries* **2012**, *20*, 281–288.
97. Branson, E.J.; Turnbull, T. Welfare and deformities in fish. In *Fish Welfare*; Branson, E.J., Ed.; Blackwell Publishing Ltd: Oxford, UK, **2008**; pp. 202–216.
98. Wootton, R.J.; Smith, C. Reproduction, fisheries and aquaculture. In *Reproductive Biology of Teleost Fishes*; John Wiley & Sons, Ltd: Oxford, UK, **2015**; pp. 357–388.
99. Folkedal, O.; Pettersen, J.; Bracke, M.; Stien, L.; Nilsson, J.; Martins, C.; Breck, O.; Midtlyng, P.; Kristiansen, T. On-Farm Evaluation of the Salmon Welfare Index Model (SWIM 1.0): Theoretical and Practical Considerations. *Animal Welfare* **2016**, *25*, 135–149.