SWIM-1.0: semantic model for overall welfare assessment of Atlantic salmon (Salmo salar L.) in sea cages – a review of basic welfare indicators

Lars H. Stien[1], Marc B. M. Bracke[3], Ole Folkedal[1], Jonatan Nilsson[1], Frode Oppedal[1], Thomas Torgersen[1], Silje Kittelsen[2], Paul Midtlyng[2], Anders Kiessling[4], Øyvind Øverli[4], Tore S. Kristiansen[1]

1. Institute of Marine Research, P.O. Box 1870 Nordnes, 5817 Bergen, Norway
2. Norwegian School of Veterinary Science, P.O.Box 8146 Dep, N-0033 Oslo, Norway
3. Wageningen UR Livestock Research, P.O.Box 65, 8200AB, Lelystad, The Netherlands
4. University of life sciences, P.O. Box 5003, 1432 Ås, Norway

Keywords: animal welfare score, fish, diagnostic, aquaculture, monitoring,

Abstract

In this study we construct a semantic model for overall welfare assessment of Atlantic salmon in sea cages. The model is designed to help fish farmers make their of assessment of fish welfare andbased on a review of selected welfare indicators. These include environment based indicators (namely water temperature, oxygen level, salinity and water current), cage specific indicators (namely stocking density, artificial lights and disturbances), animal based indicators (namely daily mortality, feed conversion, appetite, growth and disease), and individual fish based indicators (namely sea lice, body condition, emaciated fish, maturation and smoltification). We use the framework of semantic modelling to generate a structured evaluation of each indicator and to create an overall assessment model/tool? for salmon welfare in sea cages. In short, we first identify the needs of the salmon and collect statements from the literature about how and how much the welfare indicators affect fish welfare. Secondly, we link the indicators to needs to ensure that the indicators are important for welfare from the animals' point of view. Thirdly, we divide the individual indicators into levels that can be ranked from worst to best welfare and weight their impact on overall welfare. This is comprised into an overall welfare assessment schema which scores each indicator and calculates an overall welfare index. The index indicates what the overall welfare status is, but, more importantly, the schema provides a diagnostic tool to identify which indicators have contributed negatively (and positively) to the overall scoring.

Introduction

The problem of how to assess the welfare status of fish is an ongoing debate and no consensus has been reached on definitions or methodology for assessment and monitoring of fish welfare. It is clear, however that a range of welfare indicators should be considered and that indicators of fish welfare should be species specific, validated, reliable, feasible and auditable (EFSA 2009). A number of EU-projects and national projects have been or are being performed related to fish welfare. These are using a range of approaches from studies of fish behaviour to microarrays (http://ec.europa.eu/food/animal/welfare/research/index_en.htm) and a number of welfare related indicators have been suggested, but without an integrating model and theory, much confusion remains as to how the indicators can be cored, weighted and integrated into an overall welfare assessment (OWA[a]).

There are two closely related approaches for creating overall welfare assessment (OWA) models; risk analysis (EFSA 2006ab; Bracke et al. 2008) and semantic modelling (Bracke et al. 2002ab). The prime objectives of risk analysis are to identify hazards, their consequences and probabilities of occurrence, and to find critical control points in the production process to avoid suffering and disease. Semantic modelling follows a principally different approach, focussing on welfare defined as the quality of life as perceived by the animals themselves. Since semantic modelling considers both positive and negative aspects of welfare it is a risk-benefit analysis (Bracke et al. 1999abc; Bracke et al. 2008).

This paper describes a first attempt to apply semantic modelling to review commonly used welfare indicators for Atlantic salmon and to propose a science based model and tool for OWA of Atlantic salmon (*Salmo salar* L.) being farmed in sea cages. Atlantic salmon is chosen as the case species for fish given its importance in world aquaculture and since there is a reasonable amount of scientific knowledge available. The model is named SWIM-1.0, abbreviated from Salmon Welfare Index Model, no. 1 states that it is the farmer's version and .0 states that this is the original version which may be revised and upgraded later. A web application (www.imr.no/swim) was constructed in order to facilitate author collaboration when updating the model's scientific database (statements from the literature) and the model itself. The web application will also support updating the model with results from future research, such that SWIM will be a dynamic and up-to-date model. The model is primarily intended as a tool for fish farmers to assess fish welfare in sea cages, but will be expanded later with welfare indicators that can be measured by farm veterinarians (SWIM-2) and fish welfare experts (SWIM-3). For use by fish farmers it is important that the welfare indicators are limited in number, feasible and practical to use. The indicators employed in the current version and their weightings in the model may change in future versions as the knowledge of different welfare indicators expands We believe that the presented model will be a foundation for reaching consensus in how to assess overall fish welfare in sea cages.

---

[a]OWA is a systematic attempt to assess the welfare status of animals based on observations of the animals, their biological and physical environments, and available scientific knowledge (Bracke et al. 1999a; Anon. 2001).

The semantic modelling concept

The semantic modelling concept was introduced by Bracke et al. (1999abc) for the purpose of formalised assessment of animal welfare based on the meaning (semantics) of available scientific information about the animals' basic needs and how these are related to animal welfare. This includes scientific descriptions of housing systems in terms of both environment based and animal based measures, and how they affect animal welfare. Semantic modelling was first applied to assess housing systems for dry sows (Bracke et al. 2002ab), but it has also been applied to assess overall welfare in laying hens (DeMol et al. 2004, 2006; Shimmura et al. 2011), for tail biting in pigs (Bracke et al. 2004ab), for enrichment materials for pigs (Bracke et al. 2007ab; Bracke 2008), in dairy cattle (Ursinus et al. 2009) and for wallowing in pigs (Bracke 2011; Bracke and Spoolder 2011).

In view of the ongoing debate about fish welfare it is necessary to clarify definitions and underlying assumptions that semantic modelling of animal welfare rest on. First, in order to 'survive' an animal must fulfil its basic needs; e.g. nutrition, respiration, thermo regulation. To this end animals continuously assess their "state of need". This requires a monitoring system to guide the animal in getting what it needs and avoiding harm and dangers in an effective way. In advanced vertebrates, the emotional brain plays a central role. It controls all coping mechanisms, involving experience, memories and re-evaluation of needs in anticipation of physiological, psychological and behavioural requirements (Panksepp 2005; Korte et al. 2007). In this framework the ability to experience good or bad welfare is an inherent quality in individual animals with advanced central nervous systems, created by the reward and punishment systems in the brain, which have evolved as motivational and survival mechanisms (Berridge 2004). There is growing evidence that teleost fish, and hence salmon, can feel pain and that they possess functional equivalents of the limbic and dopaminergic nervous systems – systems that are linked with emotion, memory, spatial relationships, primary consciousness, reward, cost-benefit estimation and decision-making (Sneddon 2003; Chandroo et al. 2004ab; Braithwaite and Huntingford 2004; Håstein et al. 2005; Braithwaite and Boulcott 2007; Galhardo and Oliveira 2009; Johnston 2009; Braithwaite 2010). In short, there are strong scientific indications that salmon are able to experience states of welfare. Based on this we assume that salmon have a continuum of states of welfare, which may vary from very poor to excellent and that are closely related to the degree of fulfilment of the salmons' needs. An OWA should be in accordance with the needs-assessment performed by the animals themselves. However, since we cannot tap directly into the animal brain, we must assess their state of need and emotionality based on observations of the animals and what we know about the way they respond to a variety of environmental conditions. This implies using scientific knowledge about animal physiology and behaviour to surmise their welfare state (Bracke et al. 1999c).

Welfare relevant needs of farmed Atlantic salmon

We used a slightly modified version of the semantic modelling procedure described in Bracke et al. (2002a). The first step was to make a list of the farmed Atlantic salmon welfare needs, Taking the list of needs presented in Bracke et al. 1999c as a starting point we formulated a list of welfare needs for Atlantic salmon in sea cages (Table 1). The physical welfare needs include respiration, osmotic balance, nutrition, excretion, good health and thermo regulation. Behavioural welfare needs describe needs to perform specific behaviours for which the mere performance is probably rewarding. These are behaviours that have evolved to fulfil more ultimate goals related to survival, growth or reproduction (Jensen & Toates 1993). For Atlantic salmon in sea cages these needs include behaviour control, foraging, safety, protection, social contact, exploration, kinesis, rest, sexual behaviour and body care. To avoid confusion, we must emphasise that the distinction between physical and behavioural needs, and also the distinctions between needs, is not absolute and that overlaps exist.

Table 1: List of Atlantic salmons basic needs, adapted from Bracke et al., 1999c.

	Need	Explanation and relevance for salmon
Physical needs	Respiration	Uptake of oxygen and release of carbon dioxide by pumping water over the gills.
	Osmotic balance	Maintaining homeostasis of body cell fluids
	Nutrition	Intake of food containing the required energy, amino acids, minerals, vitamins etc.
	Excretion	The bodily process of discharging waste matter
	Health	Absence of disease, illness and malfunction
	Thermo regulation	Optimization of metabolism and temperature, including thermal comfort
Behavioural needs	Behaviour control	Ability of the fish to move and position themselves, including regulation of buoyancy.
	Feeding	Need to eat. Intake of nutrition (eating) and foraging
	Safety	Possibility to avoid perceived danger
	Protection	Possibility to keep the body undamaged from physical injury
	Social contact	Interaction with conspecifics.
	Exploration	Possibility to search for resources.
	Kinesis	Being able to swim and respond to stimuli
	Rest	Possibility of reducing activity level or “sleep”.
	Sexual behaviour	Homeward migration, breeding behaviour, spawning, etc.
	Body care	Scratching, parasite cleaning, etc.

Merknad [BM1]: Mb: this could be subsumed under kinesis.

Merknad [BM2]: Mb: thjis generates too much overlap with ‘ nutrition’

Linking of welfare indicators to needs

Seventeen welfare indicators were selected for inclusion in the SWIM 1 model: water temperature, oxygen level, salinity, water current, stocking density, artificial lights, disturbances, daily mortality, feed conversion ratio, appetite, growth, disease, sea lice, body condition, emaciated fish, maturation state, smoltification state, fin condition and skin condition. All the WIs were linked (Table2) to at least one of the needs (Table 1). This was done based on the literature review (see below) and to make sure that all the indicators say something about the degree of fulfilment of needs of salmon in sea cages.

Table 2: Table showing how the selected welfare indicators are linked to the needs of Atlantic salmon in sea cages based on the scientific statements (modified after Bracke et al., 2002a).

Welfare indicators \ **Needs**	Respiration	Osmotic balance	Nutrition	Excretion	Health	Thermo regulation	Behaviour control	Feeding	Safety	Protection	Social contact	Exploration	Kinesis	Rest	Sexual behavior	Body care
Water temperature	X	X	X		X	X	X	X					X	X		
Salinity	X	X		X?	X		X									
Oxygen	X				X		X?									
Water current	X						X		X			X	X	X		
Stocking density						X	X		X	X	X	X				
Artificial lights			X			X	X						X			
Disturbances	X	X					X	X	X	X				X		
Daily mortality	X	X			X	X	X	X								
Feed conversion	X	X	X		X	X		X								
Appetite	X	X			X	X	X	X								
Disease	X	X	X		X				X	X						
Sea lice		X			X		X	X	X	X						X
Condition factor			X		X			X								
Emaciated fish			X		X			X	X		X					
Sexual maturation		X	X												X	
Smoltification/Parr		X							X							
Fin condition					X					X				X		
Skin condition		X		X	X					X				X		

Welfare indicator review, ranking of levels and weighting

The next step of the semantic modelling procedure (Bracke et al., 2002a) was collect relevant scientific statements, obtained from a systematic literature review. In this review we used the selection criterion that the statements are relevant to assess the fulfilment of needs of Atlantic salmon kept in sea cages. Sources include ISI Web of Knowledge^{SM}, Google Scholar^{TM} and various books and reports on the topic (references given below). As far as possible the statements were species specific (Atlantic salmon) and for the post-smolt, sea water adapted, life stage of salmon. Based on the review the WIs were specified further in terms of levels from best to worst. These levels must be mutually exclusive and cover the model's domain, i.e. in our case on-growing of Atlantic salmon in sea cages. Each welfare-indicator level must also be linked to at least one scientific statement that provides the scientific basis of the weighting of the model. Firstly, the levels are ranked within each attribute to create indicator scores (IS):

$$\mathrm{IS}_{i,j} = \frac{\mathrm{NL}_i - \mathrm{RL}_{i,j}}{\mathrm{NL}_i - 1}, \qquad (1)$$

where $\mathrm{IS}_{i,j}$ is the score of the j-th level of the i-th welfare indicator in the model, NL_i is total number of levels of indicator i and $\mathrm{RL}_{i,j}$ is the rank number of level j. Next, the scientific evidence is used to assign weighting scores (WS) using weighting categories (WC) (Table 1).

This is a somewhat subjective, but systematic, scoring based on an assessment of the intensity, duration and incidence of the welfare impact as implied by each scientific statement that has been linked to the WI. The WC's classify welfare performance criteria, e.g. pain, illness and reduced survival (Table 1). The weighting factor (WF) of each welfare indicator *i* in the model was subsequently calculated as proposed by De Mol et al. 2006):

$$\mathrm{WF}_i = \left(\sum_{wc} \max(\mathrm{WS}_{wcl})\right)_{ILbest,i} - \left(\sum_{wc} \min(\mathrm{WS}_{wcl})\right)_{ILworst,i}, \quad (2)$$

where $\mathrm{IL}_{best,i}$ is the best indicator level and $\mathrm{IL}_{worst,i}$ is the worst indicator level of the *i*-th welfare indicator, WS_{wcl} is the weighting score assigned to the indicator level based on the scientific statements; *wc* identifies the weighting categories linked to the indicator level. A special case is made up of welfare indicator levels that are so detrimental for welfare that welfare is poor (minimum), no matter which levels are selected for the other indicators. These levels are called knockout levels, and if present OWS is defined as 0. Knockout levels are not included when calculating WFs.

Table 3: Weighting categories used in the weighting procedure of semantic modelling with brief descriptions and ranges of weighting scores (WS). Adapted from Bracke et al. 2002a

Weighting category	Brief description	Range of WS
HPI	Evidence of activation of the HPI (hypothalamic pituitary interrenal) axis indicative of distress.	-5 to -1
Illness	Evidence of health problems, including increased mortality, but excluding skin lesions, fin damage and abnormalities in body shape (see 'Pain').	-5 to -1
Pain	Evidence of pain including skin and fin damage and abnormal body shape	
Reduced survival	Evidence of reduced survival related to physiological requirements (other than through specific health problems), e.g. longevity, deprivation of food, poor environment	-5 to -1
Abnormal behaviour	Evidence of disturbed behaviour and or apathy.	-3 to -1
Aggression	Evidence of aggression such as bite marks and attacks	-3 to -1
Avoidance	Evidence of avoiding stimuli (which are perceived as dangerous/noxious)	-3 to -1
Frustration	Evidence of blocked behaviour or deprivation including willingness to avoid a treatment	-3 to -1
Negative performance	Evidence of decreased fitness (that is likely to indicate negative affect), including (re)production effects, but excluding specific survival aspects related to physiological necessities, HPA and illness.	-3 to -1
SAM	Evidence of SAM (sympathetic adrenal medullary) activation (indicative of negative affect), e.g. increased heart rate and (nor)adrenalin levels	-3 to -1
Demand	Evidence that the fish are willing to spend effort to obtain food or other recourses	1 to 5
Natural behaviour	Evidence of (potential positive reward from) behaviour as seen in (semi) natural conditions	1 to 3
Positive performance	Evidence of healthy, fit fish	1 to 3
Preference	Evidence of choosing one resource over another (e.g. in a preference test)	1 to 3

As much as possible each indicator was reviewed as stand alone, i.e. if an indicator level has an effect on another indicator the resulting change in fish welfare is attributed to the second

Merknad [BM3]: How is that diferent from 'avoidance'?

Merknad [BM4]: MB: 'performance' tends to refer to (re-)production (in an agricultural setting), whereas 'fitness' (which includes 'performance') has a slighly different focus, it refers to aspects biological functioning (primarily related to survival and reproduction in more natural environments). Eg smolitifcation may be a sign of enhanced fitness (ready to breed) but it reduces performance (cannot be sold).

indicator and not the first. For an example, high stocking densities may lead to poor oxygen levels if the water in the cage is not sufficiently replenished. The low oxygen level has a direct effect on the fish and this is the primary welfare indicator in this specific example. Each review is followed by a ranking and weighting paragraph.. The welfare indicators and weighting categories have been given capital first letters in these paragraphs for easy recognition.

Water temperature (°C)

Temperature governs the metabolic rate of salmon, and thereby acts as a controlling and limiting factor together with oxygen for the fishes' physiological performance including their capacity for dealing with stressors. The relevance of water temperature as a welfare indicator is evident from tolerance limits and temperature preferences of Atlantic salmon in sea cages.. A temperature preference in stratified sea cages of about 17 °C is suggested (Johansson et al. 2006, 2009). This corresponds well with the finding that the selected temperature in a horizontal temperature gradient increased with acclimation (5-20 °C), showing a final preference at about 17 °C (Javaid and Anderson 1967). In the available range between 11 and 20 °C, caged Atlantic salmon individuals and groups clearly avoided water warmer than 18 °C as well as water colder than 12 °C (Johansson et al. 2006, 2009; Oppedal et al. 2011b). The temperature tolerance is highly dependent on fish acclimatisation states, and in general Atlantic salmon can adapt to a range from 0 to 20-23 °C provided sufficient oxygen levels and gradual transitions exist between temperatures (Priede 2002; EFSA 2008). An Icelandic stock of Atlantic salmon survived 1 month with water temperatures less than 0° C before mortalities started to occur at -1.4° C. (Skuladottir et al. 1990). On the opposite end of the scale (Goncalves et al. 2006) observed increased mortality already at temperatures slightly above 18 °C in case of full-strength seawater (Goncalves et al. 2006). This shows that the margins are small between temperatures that salmon seem to prefer and what may be harmful to them (with exponential effects ocurring in the upper range). Comparing Atlantic salmon reared at 6, 10, 14 and 18 °C for 12 weeks following transfer to seawater, Handeland et al. (2008) found that growth rate, feed intake, feed conversion efficiency (FCE) and stomach evacuation rate were significantly influenced by temperature and fish size. The highest growth rate was seen in the 14 °C group (1.53% d^{-1}). No differences in growth were found between the 10 and 18 °C groups (1.35% d^{-1} vs. 1.29% d^{-1}), and lowest growth rates were observed for the 6 °C group (0.78% d^{-1}). However, in a recent study, 16 °C induced a long-term reduced growth rate compared to 10 °C following transfer to sea water (Grini et al. 2011). The discrepancy between temperatures for maximised growth and preferred temperatures in cages and in the ocean suggests that the distribution of salmon may be determined by other environmental factors than only temperature: Wild salmon in the ocean must stay in waters with sufficient abundance of prey, even if these temperatures are lower than preferred. In sea cages, temperatures vary vertically, as do other aspects of the environment (presence of other salmon, oxygen levels, light, pressure levels affecting buoyancy), so the chosen swimming depth should be a compromise where different environmental parameters are significant. In any case, the facts that salmon are often caught in the wild at temperatures as low as 7 °C (Holm et al., 2000) even though they have access to warmer water, and are often observed at temperatures as high as 17 °C even though they have access to cooler water imply that temperatures in the range 7-17 °C are not problematic for salmon if water quality is good and the exposure time limited or the fish have been given time to acclimatise..

Based on this review view conclude that farmed Atlantic salmon have Positive performance and Preference for temperatures in the range 7-17 °C. These are temperatures within the normal seasonal range Atlantic salmon experience in sea cages. Very high (≥18°C) and low temperatures (≤2°C) are associated with Avoidance and Negative performance. Very high and low temperatures can also be lethal if they persist for a long time (knockout). We therefore divided the Temperature welfare indicator (WI) into four levels (Table 4) and calculated a weighting factor (WF, eq. 2) of 8 (Table 5).

Salinity (ppt)

During the smoltification process salmon develop tolerance for high salinity. Adult, none-migratory Atlantic salmon is little affected by salinity (Bakke et al. 1991; Johansson et al. 2006; 2009), unless damage to the skin and disease impair their osmoregulatory ability (Grimnes and Jakobsen 1996; Boxaspen 2006). Mature salmon have altered osmoregulation in adaptation to a hypo-osmotic environment before re-entering freshwater in nature (Persson et al. 1998) and may therefore experience osmoregulatory challenges in high salinities. Small salmon display a preference for the halocline (Oppedal et al. 2011a) and may, therefore, benefit from access to brackish water as osmoregulation is relatively costly for small salmon. Swimming in brackish water may also help the salmon to avoid infection from sea lice (*Lepeophtheirus salmonis*) (Hevrøy et al. 2003; Plantalech Manel-La et al. 2009) as the infectious larvae of sea lice do not tolerate low salinities (Bricknell et al. 2006). Salinity has been suggested as a factor regulating swimming depth in adult salmon, but current evidence suggests that salinity is unimportant in determining vertical distributions in immature fully smoltified seawater-transferred Atlantic salmon (Johansson et al. 2006; 2007; Oppedal et al. 2011a).

To conclude, there is little evidence that salinity levels have significant effects on the welfare of adult Atlantic salmon. Some studies do, however, indicate that small, newly seawater transferred salmon may show a Preference to brackish water, perhaps to avoid sea lice or to regulate osmotic balance. Furthermore, sexually mature salmon may have impaired osmoregulatory capacity. In a sea cage containing 10-100.000 fish it is likely that some fish, for one or more of the above reasons, have compromised osmotic balance. For these fish the inability to have access to brackish water may lead to Negative performance and Reduced survival. We suggest two levels for the Salinity WI (Table 4). In accordance with limited evidence for a strong effect on fish welfare the calculated WF is only 3 (Table 5).

Oxygen saturation (%)[b]

The amount of oxygen that dissolves in seawater decreases with increasing water temperature and salinity (e.g. Hansen 1999) (Figure 1A). Atlantic salmons' relative (per weight unit) oxygen need increases with temperature and swimming speed, and decreases with body size (Fivelstad and Smith 1991; Forsberg 1994; Grøttum and Sigholt 1998; Stevens et al. 1998) (Figure 1B).

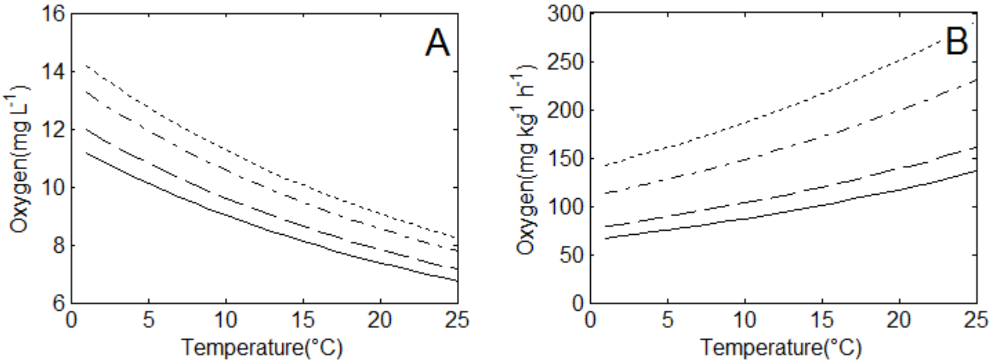

Figure 1: A) Relationship between oxygen content, temperature and salinity in 100% saturated sea water. The dotted line represents a salinity of 0 ppt, the dotted-dashed 10 ppt, the dashed 25 ppt and the solid line 35 ppt. B) Relationship between oxygen consumption, temperature and fish size according to the model by Grøttum and Sigholt (1998) at a swimming speed of 1 body lengths s^{-1}. The dotted line represents a fish size of 0.5 kg, the dotted-dashed 1.0 kg, the dashed 3.0 kg and the solid line represents a fish size of 5.0 kg.

Stevens et al. (1998) found that the routine oxygen uptake of juvenile Atlantic salmon in freshwater at 12-13°C was not limited by water oxygen saturations above 38%. This was confirmed in recent studies in sea water, (Torgersen et al. 2010; 2011b; reviewed in Oppedal et al. 2011a) showing that at 18, 12 and 6 °C 400 g salmon post-smolt are not able to maintain routine metabolic rates below 60, 40 and 28% saturation, respectively. Below these thresholds mortality will commence in farmed salmon if oxygen levels are not improved. The difference between the routine and the maximum metabolic rate, i.e. the theoretically possible oxygen

[b]Oxygen levels are usually reported as concentration (normally mg L^{-1}) or saturation (as percentage of oxygen saturation relative to water at equilibrium with air at 1 atm pressure). These measures are of course related, but as oxygen solubility decreases with temperature and salinity, the oxygen concentration corresponding to any level of oxygen saturation varies. Both concentration and saturation are meaningful metrics of available oxygen in the water. Any oxygen that is to be utilized by fish tissues must be extracted from the water ventilated by the fish over its gills, and at any given saturation, cooler and less saline water contains more oxygen. However, the diffusion of oxygen over the gills and the binding of oxygen to the haemoglobin are driven by oxygen saturation, so at any given concentration of oxygen, the availability of the oxygen for uptake is higher in warmer more saline water. Both measures are in other words useful WIs, but saturation is normally considered to be the most relevant measure in sea cages. Another reason for using saturation as the operational welfare indicator is that intuitive inferences can be drawn from saturation levels without any knowledge about temperature, salinity and solubility: an oxygen saturation of 80% tells us that the fish is offered 80% of normal environmental oxygen saturation levels.

uptake under the present condition, acts as a buffer against factors such as stress, disease and feeding, which narrow this metabolic scope (e.g. Helfman et al. 1997; Priede 2002). A summary from several hypoxia trials (WEALTH 2008) concluded that immune responses are reduced at levels below 55% oxygen saturation, and Sundh et al. (2010) found that the intestinal function was clearly disturbed at a level of 50% for salmon kept at both 9 °C and 16 °C. A report from the Norwegian Food Safety Authority (Rosten et al. 2004) states that a level of 50% oxygen saturation is an absolute minimum, but recommends levels between 80-100% in sea cages. Similarly, EFSA (2008) states that oxygen saturation below 60% creates welfare problems for Atlantic salmon, and levels from 80% to 50% give a gradual reduction in feed intake and growth. This is in line with studies by Crampton et al. (2003) and Bergheim et al. (2006) who found that salmon displayed reduced growth at moderate environmental hypoxia (75% oxygen in 9°C water and 85% in 15 °C water, respectively) compared to fish kept at normal environmental oxygen-saturation levels (100%). This high sensitivity of growth rate to oxygen availability suggests that even modest reductions in oxygen saturation may start causing welfare problems.

Based on this review it clear that oxygen levels above 80% do not cause welfare problems for salmon in sea cages and are associated with Positive performance. Below 80% a gradual increase in Negative performance and Survival may be observed, especially if the water temperature is high. We therefore divided the Dissolved oxygen (DO) WI into four levels (Table 4), including one knockout level and calculated a WF of 9 (Table 5).

Water current (measured as body lengths s^{-1})

The water flow through a sea cage replenishes oxygen used by the fish and flushes out metabolites and suspended solids such as faeces and excess feed (EFSA 2008; MacIntyre et al. 2008). The swimming capacity of Atlantic salmon depends on factors such as body size and metabolic scope (Grøttum and Sigholt 1998). Data about critical swimming speed U_{crit} in swimming tunnels indicate that salmon can maintain long-term swimming speeds at 0.5 body lengths (BL) s^{-1} (McKenzie et al. 1998) and observations from sea cages confirm that during daytime salmon cruise at 0.3-0.9 BL s^{-1} (Juell 1995; Dempster et al. 2008, 2009; Korsøen et al. 2009), while they typically slow down during darkness to 0-0.4 BL s^{-1} (Korsøen et al. 2009). Salmon reared in raceways with a fixed current (28 cm s^{-1}, 0.40 to 0.45 BL s^{-1}) for 8 months prior to harvest showed nearly 40% higher weight gain compared to control fish farmed in ordinary cages (Totland et al. 1987). Exercise may have prophylactic effects on hypoxic conditions and strengthen the immune robustness in general (Takle et al. 2010) and improve cardio-vascular capacities (Jørgensen and Jobling 1994; Davison, 1997). Although water current typically is measured as m s^{-1}, in regards to fish welfare it makes more sense to measure it as BL s^{-1}. High currents can drive small salmon (400-800g) to exhaustion already at 1.6-2.2 BL s^{-1} (McKenzie et al., 1998; Deitch et al., 2006), although some can manage 3.0 BL s^{-1}(Powell and Lijalad, 2009). We were unable to find data on larger Atlantic salmon, but studies in Sockeye salmon (*Oncorhynchus nerka*) indicate an U_{crit} of about 1.35 BL s^{-1} for larger salmonids (Steinhausen et al. 2008). It should be noted that the above studies using swimming tunnels were performed on starved fish and that fully-fed, commercial fish probably have lower thresholds due to less available scope for activity.

The water flow through sea cages must be sufficient to secure replenishment of oxygen. While saturation with oxygen per se is a separate welfare indicator, water currents also affect swimming speeds of the fish. At moderate levels these may be positive for welfare (provide 'exercise'), but at higher values welfare may be reduced, and when the water velocity is so high that it exceeds critical swimming speed (U_{crit}) then water flow may even be lethal for the fish (knock-out). From the literature review salmon appear to be able to maintain Natural behaviour up to about 0.6 BL s^{-1}. We were not able to find any literature about swimming speeds between the comfort zone and the U_{crit}s (pending size), but it is reasonable to assume that forced swimming leads to loss of control and hence Frustration over time. It is also reasonable to assume that U_{crit} in addition to size depend on the state of the fish, for instance how adapted it is to high water currents. The farmer must, in other words, know the ability of the fish or use an U_{crit} of 1.3 for safe margins. We suggest dividing the Water current WI into three levels (Table 4) with a WF of 3 (Table 5).

Stocking density (kg m^{-3})

Stocking density, defined as the total biomass of the fish divided by the sea cage volume, is typically used by authorities to set upper limits for what is allowed in sea cages (e.g. 25 kg m^{-3} in Norway). Despite its frequent use as a production parameter there are relatively few studies on how different stocking densities affect salmon in sea cages. Turnbull et al. (2005) examined densities ranging from 10 to 34 kg m^{-3} at a sea farm and found no negative effects on the salmon, measured as a combined score of body condition, fin condition, plasma glucose, and cortisol, up to an inflection point at about 22 kg m^{-3}, and no substantial negative effect on these parameters below 32 kg m^{-3}. These findings were largely confirmed in a tank study by Adams et al. (2007) and a sea cage study by Oppedal et al. (2011). Adams et al. (2007) found negative effects on welfare for a stocking density of 35 kg m^{-3} compared to 25 kg m^{-3}, and Oppedal et al. (2011b) found declined feed intake, growth rate, feed utilisation and a greater number of cataracts when the stocking density exceeded 26.5 kg m^{-3}. Unfortunately, these three studies provide limited information about the oxygen saturation of the water or the presence of endemic infections, which both may have been important reasons for decreased fish welfare at the higher densities (Johansson et al. 2006; Oppedal et al. 2011b). A tank study indicates that low stocking densities of only 57 individuals may lead to aggression and reduced welfare (Adams et al. 2007), but this has not been confirmed for low densities in sea cages holding higher number of individuals (Turnbull et al. 2005; Johansson et al. 2006; Oppedal et al. 2011b). Johansson et al. (2006) showed that salmon in sea cages at high stocking densities (18-27 kg m^{-3}) have limited abilities to position themselves at preferred temperatures compared to fish at lower densities (7-11 kg m^{-3}) and as a result grew less. Oppedal et al. (2007; 2011b) showed that salmon may congregate into very tight schools, with a local density above 180 kg m^{-3}, in order to be at a preferred temperature.

Although the literature shows that salmon may congregate at extreme densities, it seems clear that high overall densities limit the fish's freedom to move in the cage. Stocking densities below 22 kg m^{-3} have been suggested to be optimal, and at higher densities welfare becomes incrementally worse until above 32 kg m^{-1}, where there is a substantial effect on Negative performance, Pain and Illness. We divided the Stocking density WI into four levels from <22 kg m^{-3} to above 32 kg m^{-3} (Table 4) and calculated a WF of 5 (Table 5).

Artificial lights

Underwater lights are widely used in the industry to reduce the incidence of sexual maturation (e.g. Hansen et al. 1992; Oppedal et al. 1997; Taranger et al. 1999; Porter et al. 1999; Peterson and Harmon 2005; Oppedal et al. 2006; Guerrero-Torolero and Bromage 2008; Leclerq et al. 2010; 2011) and also to increase growth (e.g. Nordgarden et al. 2003; Oppedal et al. 2003; Oppedal et al. 2006; Leclerq et al. 2010). In the first year of autumn-transferred smolts an artificial light regime of natural photoperiod (NL) until January and artificial light (LL) until midsummer is recommended (Oppedal et al. 2006). For spring-transferred smolt artificial light (LL) is generally used from mid-winter to mid-summer with up to two months deviation in commencement and end (Hansen et al. 1992; Oppedal et al. 1997; Porter et al. 1999) with a recent study indicating that 4 months of LL is sufficient. Early studies using surface lights in sea cages had variable results in regard to both grilsing and growth (Kråkenes et al. 1991; Hansen et al. 1992; Porter et al. 1999; Taranger et al. 1998; 1999; Endal et al. 2000). This may derive from differences in cage size and how well the sea cage volume was illuminated (Oppedal et al. 1997; 2007; Leclerq et al. 2011). Studies in tanks, however, universally show increased or equal growth while levels of sexual maturation are variable and often comparable to natural light (Björnson et al. 1994; Forsberg 1995a; Berg et al. 1996; Oppedal et al. 2003; Nordgarden et al. 2003). A reduced growth and appetite during the first weeks after deployment of lights have been reported (Hansen et al. 1992; Taranger et al. 1995; Endal et al. 2000; Oppedal et al. 2003; Nordgarden et al. 2003) and recent findings show that very high light intensities can induce an acute transient stress response (Wallace et al. 1988; Migaud et al. 2007) and even retinal damage (Vera and Migaud 2009). Atlantic salmon tend to avoid strong surface daylight (Fernö et al. 1995), but are attracted to night-time surface and underwater lights (Juell et al. 2003; Juell and Fosseidengen 2004; Oppedal et al. 2007; 2011a). Lighting the cage at night stimulates the salmon to maintain daytime swimming speeds and schooling behaviour, but the use of only surface lights may result in fish swimming at very high densities near the surface (Juell et al. 2003). Using submersible lights at depths (e.g. 15 m) that allow the salmon to spread out both above and below the lights may, therefore, be a measure that improves the welfare of caged salmon (Juell et al., 2003, Juell and Fosseidengen 2004; Oppedal et al. 2007; 2011a).

To conclude, Atlantic salmon has a Preference for positioning according to the depth of subsurface illumination. With narrow illumination of the cage volume (suboptimal), such as artificial lights positioned at only a shallow depth or above the surface, the salmon may be forced to school at high densities near the surface at night time and experience Frustration and Avoidance as other depth layers are not used. Artificial lights at multiple depths (optimal) or natural daytime light conditions allow the salmon to utilise the entire water column and hence contribute to Positive performance. The Artificial lights WI was, therefore, divided into three levels: optimal use (consisting of multiple lamps positioned at multiple depths to secure illumination of the preferred depth in stratified waters) sub-optimal use (not sufficiently covering the preferred volume) and worst level (lack of artificial illumination when it should be applied in order to prevent sexual maturation at a later stage; see Table 4), and WF calculated as 6 (Table 5).

Disturbances

Removing fish from the water, for instance when estimating level of sea lice infestation, is one of the most severe stress events, and induces a high cortisol response (Schreck 1997). However, this is usually done on only a few individuals at a time and likely to have little effect on the other fish in the cage. Other procedures may affect the whole group, e.g. delousing by bath (Vigen 2008; Nilsen et al. 2010), grading (Juell et al. 2008) and transportation (Iversen et al. 1998; 2005; Farell et al. 2005). Studies of wellboat-transportation of smolt (Iversen et al. 2005) and live-hauling of harvest fish to processing facilities (Farrel et al. 2005) show that during transport salmon recover from the initial handling stress of being loaded. This recovery seems to be crucial to avoid cumulative and hence long-term stress during their initial period in the sea cages (Iversen et al. 2005). Juell et al. 2008 observed that crowding, pumping and sorting of salmon in sea cages lead to a rapid drop in oxygen levels (not critical) during the procedure. For several days the fish were also more dispersed in the cages than before the treatment and they did not concentrate as much in the warm surface layers as before. Appetite was reduced for approximately 5 days, and did not increase with the increasing surface temperatures in May, indicating a strong negative effect of this commercial sorting procedure. During delousing with bath treatment a bottom opened or closed tarpaulin "skirt" is placed around the cage to keep the therapeutic chemicals inside the cage. Various aspects of this procedure, including the disturbance, crowding, changed environment, skirt and the treatment substance, may affect the fish. Vigen (2008) found that in a group of salmon held at 25 kg m^{-3} the oxygen saturation decreased to around 50% within 45 minutes after a skirt was placed around the cage, when no treatment substance was added. After the treatment substance (the pyretroid cypermethrin, Betamax Vet) had been added within the skirt, salmon crowded at very high densities (up to 107 kg m^{-3}) near the surface. Oxygen saturation decreased faster while swimming speed and gill ventilation frequency were higher and more variable. In a compilation of observations during topical delousing with skirts which were open at the bottom Nilsen et al. (2010) concluded that the salmon were swimming below the enclosed volume when the nets were not lifted. Following delousing, many farmers have reported poor performance of the fish including poor appetite, reduced growth, disease outbreaks and increased mortalities.

Severe disturbances such as pumping of the fish may lead to Abnormal behaviour, Negative performance, Illness and Reduced survival. Moderate disturbances as crowding and topical delousing affect welfare to a lesser extent. It is also likely that light disturbances (activity around the cage) may stress the fish to some extent, and that no disturbances promote Natural or normal cage behaviour. We, therefore, propose to divide the Disturbances WI into four levels from non to severe disturbance and calculate a WF of 8.

Daily mortality rate (% day^{-1})

Mortality in farmed animals, including salmon, is an indicator of disease outbreaks, poor environmental conditions, or injuries, all conditions that are related to reduced welfare. Aunsmo et al. (2008) studied fish mortalities in 20 cages (10 sites) in the three first months after transfer and found that the fish died from various reasons including incomplete smoltification (5.6%), precocious males (3.3%), trauma (18.2%), specific diseases (65.6%) and unknown reason (7.6%). Cage mortality rates were not normally distributed and 73% of

Slettet: There are
Slettet: S
Slettet: s
Slettet: everal management procedures may be
Slettet: that are
Slettet: stressful for the fish.
Slettet: s
Slettet: ,
Slettet: ant
Slettet: Both the effect of
Slettet: With
Slettet: of
Slettet: (
Slettet: in
Slettet: swam
Slettet: exemplified as
Slettet: and
Slettet: a limited
Slettet: welfare indicator
Slettet: These observations strongly suggest that delousing is an aversive and stressful event
Slettet: situation
Slettet: for salmon (Oppedal et al. 2011a).
Slettet: recent states of
Slettet: and these usually indicate
Slettet: poor/
Slettet: ,
Slettet: y

the recorded mortalities occurred in only 20% of the cages. The best performing sea cages had a mortality rate, defined as number of dead fish divided by the total number of fish in the cage multiplied by hundred, of about 0.002% day^{-1}, while the worst cages had periods of mortality rates with peaks of up to 2.4% day^{-1} with an average of 0.1% day^{-1}. In an extensive study of more than 88 production cycles in Scotland within one company, Soares et al. (2011) developed benchmark mortality curves (Figure 3A). It starts above 0.1 % day^{-1} mortality during the first week after transfer, between 0.01 and 0.1 % during week 2 to 40, and then less than 0.01 % day^{-1} until slaughter. Using this benchmark a total mortality of about 11% will result at the end of production (Figure 4B). This is considerably better than the total mortality value of 17% reported by the Norwegian salmon industry and the 21% reported by the Scottish Industry (Aunsmo et al. 2008). The main causes of mortalities in Soares et al. (2011) were disease (31%), production factors[c] (29%), environment (8%), predation (7%) and other causes (26%).

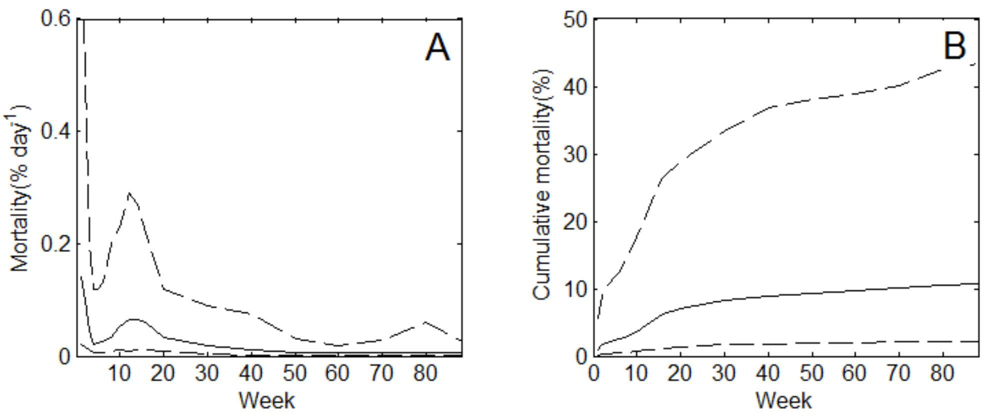

Figure 2: Benchmark for daily mortality developed by Soares et al. (2011). A) Daily mortality and B) cumulative mortality from transfer to the end of the production cycle. Solid line: Benchmark. Dashed lines 90 and 10 percentiles around benchmark. Delete B)?

Specific growth rate and feed conversion ratio

Farmers suggest that specific growth rate (SGR) and feed conversion ratio (FCR) are practical and meaningful means to assess fish health (North et al. 2008). SGR[d] is commonly used and defined in the literature as: $SGR = 100(\ln(w_2)-\ln(w_1))(t_2-t_1)^{-1}$, where w_1 and w_2 are the body weights (g) at times t_1 and t_2, the difference t_2-t_1 is calculated in days (Sinnot 2002). FCR is defined as the amount of delivered feed (g) divided by the body mass (BM) gain over a specified period of time: $FCR = feed(BM_2-BM_1)^{-1}$. With BM_1 and BM_2 at times t_1 an t_2, respectively. The thermal growth coefficient (TGC) attempts to predict growth rate independent of fish weight and temperature: $TGC = 1000(w_2^{1/3} - w_1^{1/3})\, T^{-1}(t_2-t_1)^{-1}$, where T is the temperature in °C. An old benchmark study for growth at different sizes and temperatures

[c] Includes: Accident loss, caught in net, cull, failed smolts, jacks, mature, net tear, parr, precocious male, transfer, treatment kill, smolt transfer, suspected cannibalism.

[d] Fish farmers and fish feeding companies sometimes use SGR defined as $SGR' = 100((w_2 \times w_1^{-1})^{1/(t2-t1)}-1)$ together with FCR to derive feed ration (FR, kg feed per kg fish): $FR = SGR' \times FCR$ (Anon 2009).

Slettet: daily
Slettet: that day
Slettet: a
Slettet: per
Formatert: Hevet
Slettet: daily
Slettet: characterised by peaks
Slettet: a standard
Slettet: This benchmark
Slettet: Mortality time series below the benchmark are considered to have low mortality, and time series above the benchmark to have a high. By following the
Slettet: be the
Slettet: significantly
Slettet: as
Slettet:
Formatert: Engelsk (Storbritannia)
Formatert: Utheving
Slettet: S
Slettet: suggested by fish farmers as a
Slettet: of
Slettet: ing
Slettet: a
Slettet: measure of growth
Slettet: Confusingly, fish farmers and fish feeding companies sometimes use SGR defined as $SGR' = 100((w_2 \times w_1^{-1})^{1/(t2-t1)}-1)$ together with FCR to derive feed ration (FR, kg feed per kg fish): $FR = SGR' \times FCR$ (Anon 2009).
Slettet: There is a
Formatert: Engelsk (Storbritannia)
Formatert: Engelsk (Storbritannia)
Formatert: Engelsk (Storbritannia)

(Austreng et al. 1987) resulted in this model (Forsberg 1995a): SGR = $0.9T \times w^{-0.34}$. Unfortunately, this model is limited to salmon of less than 3 kg body weight and it applies only to temperatures between 4 and 14°C. Fortunately, feed companies usually supply the farmers with expected SGR for the given feed (Sinnot 2002, Anon, 2009)(Figure 4A). Reduced SGR can indicate environmental stress (Pickering 1993; Nordgarden et al. 2003) and disease (Ersdal et al. 2001). Both SGR and TGC are dependent on photoperiod (Nordgarden et al. 2003), but this is not so pronounced for FCR (Nordgarden et al. 2003). Increased FCR can indicate underfeeding or overfeeding, a palatability problem, the onset of a health problem such as pancreas disease (PD) or stress (Sinnot 2002; Nordgarden et al. 2003; Aunsmo et al. 2010). Also, during an outbreak of HSMI (viral heart and skeletal muscle inflammation), those salmon that had a lower FCR had overall better health (Alne et al. 2009). FCR is highly dependent on water temperature and fish size (Figure 4B). An expert panel (Aunsmo et al. 2010) postulated an increase in FCR of 0.14 (range: 0.06 to 0.22) in case of PD.

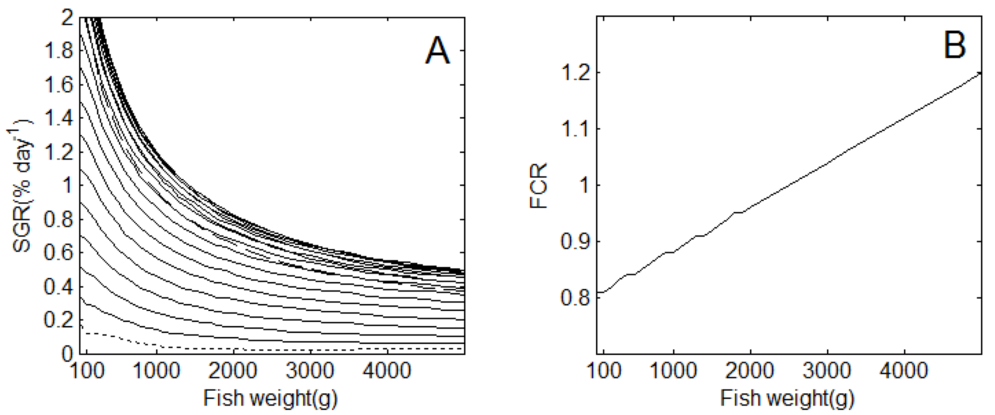

Figure 3: A) Relationships between specific growth rate (SGR') and fish weights for a number of different temperatures (Anon, 2009). Each line is for a given temperature starting from below at 1 to upper most line at 20 °C. B) FCR data for the same model. [idem copy rights?]

Appetite

Appetite is defined here as the fish's willingness to eat, and the loss of appetite may be a sign of one or more underlying welfare relevant conditions (Schreck 1997; Huntingford et al. 2006). Several studies have reported loss of appetite at infection or disease (Rodger and McArdle 1996; Damsgård et al. 2004), handling (McCormick et al. 1998), a deteriorating environment (Bergheim et al. 2006; WEALTH 2008) and high stocking density (Oppedal et al. 2011b). Many fish farmers use appetite to determine feeding levels. It requires experience in order to interpret the behaviour of the fish. The farmer must assess appetite in relation to water temperature and fish size. Appetite increases with water temperature and decreases with fish size (Austreng 1987). Feed companies usually supply farmers with expected amounts of feed under different water temperatures and fish sizes (see above). Feeding level is also linked to illumination. The responsiveness to food varies with time of day and season (Kadri et al. 1991; Jørgensen and Jobling 1992; Smith et al. 1993) and), and it may be manipulated using

Slettet: and a
Slettet: based on this study
Slettet: or
Slettet: , and
Slettet: /in?
Slettet: -outbreak
Slettet: with
Slettet:
Formatert: Engelsk (Storbritannia)
Formatert: Utheving
Slettet: ,
Slettet: Appetite is defined here as the fish's willingness to eat. Loss of appetite is a sign of potentially impaired welfare (Schreck 1997; Huntingford et al. 2006).
Slettet: ¶
Many fish farmers use appetite to determine feeding levels. It requires experience
Slettet: in order
Slettet: to interpret the behaviour of the fish. The farmer must assess appetite in relation to water temperature and fish size.
Slettet: A
Slettet: the
Slettet: throughout the
Slettet: natural

artificial photoperiods (Taranger et al. 1995; Nordgarden et al. 2003; Oppedal et al. 2003). Although feeding regime in general seems to have little effect on growth and FCR (Sveier and Lied 1998) suppressed growth was seen in daily feeding regime of 1 meal compared to 8 meals in the period just following sea transfer (Flood et al. 2011). Today, many Norwegian Salmon farmers use a camera positioned beneath the feeding area, looking up, to assess appetite levels; when the farmer sees pellets reaching down to the camera the feeding is turned off.

Disease

"The freedom from pain, injury and disease" is a widely accepted goal for good animal welfare, being one of the so-called "five freedoms" that characterise good animal welfare (http://www.fawc.org.uk/freedoms.htm). Originting from the so-called "Brambell report" (1965), the prevention of disease or injury, and their rapid diagnosis and treatment must be considered an essential part of good animal welfare in all farm animals, including farmed salmonids.

Being reared in open sea cages, sea farmed Atlantic salmon cannot evade the risk of attracting viral or bacterial infections or parasitic infestations that transmit via the water or through other means of contact with wild fish species or other reservoirs. However, the intermediate or latent infection with infectious agents does often not produce welfare relevant consequences to the fish. A similar situation exists for non-infectious diseases and disorders, where predispositions or minor developmental aberrations may exist without producing ill physiological effects. The presence of clinically manifest disease symptoms and signs, and in particular measures of morbidity or mortality is therefore proposed an important welfare indicator of sea farmed Atlantic salmon. While mortality may be near 100% attributable to a defined cause during disease outbreaks, studies of Atlantic salmon post-smolts in the absence of specific epidemics showed more than 60% of the mortality being due to specific diseases (Aunsmo et al. 2008). MÅ SKRIVES OM!

Sea lice

Farmed Atlantic salmon are parasitized by two species of sea lice; *Lepeophtheirus salmonis* (salmon lice) and, to a lesser extent, *Caligus elongates* (e.g. Pike and Wadsworth 1999). Salmon respond to a sea lice infestation with primary stress responses including elevated blood cortisol and glucose (Bowers et al. 2000; Finstad et al. 2000). These stress responses occur even though at the infective copepodid stage the lice do not yet feed on the salmon (e.g. Finstad et al., 2011). Grimnes and Jakobsen (1996) did not find severe effects on the fish from extreme infections of sea lice (>6 lice g^{-1} fish) at the copepod and early chalimus stages, but they did find a sudden increase in mortality after the appearance of the pre-adult stages. This result was confirmed by Finstad et al. (2000). Responses to an infestation of pre-adult and adult sea lice include a primary stress response, inflammatory responses, changes in appetite, changes in the skin and gills, compromised immunity, delayed healing of injuries, osmotic problems and tissue self-destruction (Nolan et al. 1999; Bowers et al. 2000; Finstad et al. 2000; Ross et al. 2000; Boxaspen 2006; Skugor et al. 2008). Strong indications exist that sea

Slettet: also be seasonally advanced or delayed by

Merknad [BM5]: MB: what do you mean?

Slettet: sea

Slettet: to the sea

Slettet: As a WI it is important to note that feeding regime can? change the behaviour of the fish indicating appetite levels to the farmer.

Formatert: Engelsk (Storbritannia)

Slettet: observe feeding behaviour/

Slettet:

Slettet: Several studies have reported loss of appetite at infection or disease (Rodger and McArdle 1996; Damsgård et al. 2004), handling (McCormick et al. 1998), a deteriorating environment (Bergheim et al. 2006; WEALTH 2008) and high stocking density (Oppedal et al. 2011b).

Formatert: Skrift: Kursiv

Formatert: Skrift: Kursiv

Formatert: Skrift: Kursiv

Slettet: Disease outbreaks may severely affect for salmon welfare in sea cages. It is outside the scope of this paper/model to conduct/perform

Slettet: do

Slettet: a detailed analysis of the different diseases that may occur, but we will provide a brief evaluation of the most common diseases and

Slettet: in

Slettet: their overall impact on

Slettet: for

Slettet: salmon

Slettet: in an infected cage

Slettet: .

Slettet: ... (I will ask Paul to write this chapter, Lars)

Slettet: ¶
¶
Early draft/brainstorm DELETE:¶
"Disease outbreak is severe for salmon welfare in sea cages. It is outside the scope of this text to do a detailed analysis of the different diseases that may occur, but we will try to do a brief evaluation of th ... [1]

Slettet: as

Slettet: ,

Merknad [BM6]: MB: 3 lines do ... [2]

Slettet: the lice

Formatert: Engelsk (Storbritannia)

Slettet: ,

Formatert: Engelsk (Storbritannia)

Slettet: There are s

lice initiate physiological problems for the host already at 0.05-0.1 lice g^{-1} fish (Nolan et al. 1999; Wagner et al. 2008) and that the host is at risk of disease at infestations rates above 0.5 lice g^{-1} fish (Wagner et al. 2008). Grimnes and Jakobsen (1996) found that more than 0.75 lice g^{-1} fish was lethal. Since a wild smolt leaving the coast has a weight of about 15 g (Finstad et al. 2000), this implies an upper limit of 11.3 lice per fish. An extensive ten year sampling of wild Atlantic salmon in the Norwegian sea revealed no fish carrying more than 10 adult lice (Holst et al. 2003), and in a study of naturally-infected salmon smolts only fish carrying 11 lice or less survived (Holst et al. 2003).

Condition factor

Condition factor (K) is a standard measurement of fish nutritional status (Bolger and Collony 1989; Nash et al. 2006) and calculated as $K = (WL^{-3})100$, where W is the weight in g and L is length in cm (e.g. Busacker et al. 1990). In general terms, a skinny salmon may have a K<0.9 and a fat fish has a K of 1.5 (Tvenning 1996). During the production cycle K changes from just above 1 as smolt (O'Flynn et al. 1997; Mørkøre and Rørvik 2001; Oppedal et al. 1999; 2006; Fjelldal et al. 2009ab) to 1.6 nearer slaughter (Einen et al. 1998; Rørå et al. 1998; Oppedal et al. 1997; 1999; 2006; Mørkøre and Rørvik 2001) but this may partly be overruled by season phase and delayed by artificial photoperiods (Oppedal et al. 1997; 1999; 2003; 2006; Fjelldal et al. 2009ab). Generally, K values decrease during winter and spring, and increase during summer and autumn. Periods of good growth typically increase K (Juell et al. 1994; Endal et al. 2000) while periods of poor growth resulting from starvation or underfeeding reduce K (e.g. Juell et al 1994; Einen et al. 1999) and salmon may be starved down to 1.3 prior to slaughter (Einen et al. 1998). Also, sea transfer as spring or autumn smolts may interfere with the seasonal pattern (Mørkøre et al. 2001), but not inevitably (Fjelldal et al. 2009b). Farmed fish display higher K compared to hybrid and wild salmon given similar farming conditions (Fjelldal et al. 2009b). There is a strong and significant positive correlation between K and total lipid content in Atlantic salmon (Herbinger 1991; Einen et al. 1998; 1999; Rørå et al. 1998; Hamre et al. 2004; Peterson and Harmon 2005). K is negatively correlated with plasma glucose and cortisol (Turnbull et al. 2005). Very high K (>1.6) indicates spinal deformation (Gjerde et al. 2005; Witten et al. 2005; Berg et al. 2006; Fjelldal et al. 2009a; Hansen et al., 2010), but the specific level as of which this may occur is difficult to fixate due to the variations discussed above. However, within a population, low K individuals tend to be emaciated fish while "normal" K indicate health, and very high K values often indicate deformed individuals.

Emaciation state

Fish may become emaciated due to disease (e.g. Stephen and Ribble 1995; Kent and Poppe 2002), poor smoltification (Duston 1994), "wrong" feeding strategy (at transfer some fish may start to eat zooplankton instead of pellets) (pers. obs., wild smolt: Rikardsen et al. 2004), sea lice (e.g. Finstad et al. 2011), stress (e.g. Huntingford et al. 2006) and social constraints (Jobling and Reinsnes 1986; Adams et al. 2000). Emaciated fish are generally small fish of poor health, and they may act as a vector for introducing disease to the other (more healthy fish) in the cage. As they are feeding poorly, or not at all, it is difficult to treat them orally (Coyne et al. 2006). Emaciated fish are well known to fish farmers (Stien et al. 2009; Anon 2011), but there is little published research on the subject. In a study using Floy anchor tags

Slettet: condition
Merknad [f7]: Bruk Brett eller noe? Dette er jo referanse til et norkst magasin?

Lars: Norsk bok i fiskeoppdrett
Formatert: Engelsk (Storbritannia)
Formatert: Engelsk (Storbritannia)
Formatert: Engelsk (Storbritannia)
Slettet: be [?]
Slettet: ,
Slettet: d
Slettet: adult [?]
Slettet:
Slettet: H
Slettet: er
Slettet: may [however, also?]
Slettet: the occurrence of
Slettet: s
Slettet: /at
Slettet: deterimine
Slettet: /settle on
Slettet: may
Slettet: a
Slettet: may
Slettet: a
Slettet: y fish
Slettet: a
Slettet: include
Slettet: fish
Slettet: Emaciated fish
Slettet: disease (e.g. Stephen and Ribble 1995; Kent and Poppe 2002)
Slettet: h
Slettet: also increase the risk of disease affecting

on farmed chinook salmon (*Oncorhynchus tshuwytscha*) individuals that could be captured with a dip net from the surface, were mostly emaciated moribund fish (62% died within 24h) (Stephen and Ribble 1995). Characteristic for these fish were obvious pathological and clinical abnormalities (95% of 366 individuals exhibited gross and/or histopathological abnormalities), and behavioural abnormalities such as swimming into the nets or in circles, swimming separated/apart from the main group, and staying at the surface for prolonged periods of time.

Sexual maturity state

Sexual maturation leads to allocation of energy towards gonad build-up and migration. Prior to upstream migration wild salmon have an energy loss of about 60% of their body reserves (Jonsson et al. 1997; Fleming 1998). In the wild few survive to breed another year (Fleming 1998). Consequently, sexual maturation is detrimental for salmon production, where artificial photo-regimes are used to prevent maturation (see artificial lights). Sexually mature parr, precocious males, can be present at sea transfer and their presence is linked to increased mortality (Aunsmo et al. 2008). The energy expended for maturation and spawning increases with fish size and males also expend less on gonads compared to females (ca 4% vs. ca 28% of total energy reserves, Fleming 1998). This may explain why precocious males may survive and grow similarly to the immature fish (Saunders et al. 1982).Whether mature salmon have a behavioural need to carry out spawning migration is difficult to answer (c.f. Huntingford et al., 2006), but it is plausible that there is an increase in aggression leading to more fighting and biting (Fleming and Einum, 2011). With regards to altered osmoregulation in adaptation to a hypo-osmotic environment before entering freshwater in nature Persson et al. (1998) found that salmon caught in the estuary (not yet entered the river) had already adapted to a hypoosmotic environment and that during the upriver migration the gill Na+, K+-ATPase activity decreased even further. It is therefore plausible that mature salmon in sea cages to some extent experience osmoregulatory challenges. Besides the energy draining effects of maturation, it has been shown that compared to immature fish mature salmon have higher prevalence of the parasite *Kudoa thyrsites*, that is a cause of post mortem soft flesh (St-Hilaire et al. 1998).

Smoltification state

During the smoltification process the salmon parr develop tolerance for high salinity, enabling the young salmon (now called smolt) to enter seawater with only minor disturbances in osmotic balance (e.g. Stefansson et al. 2008; Thorstad et al. 2011). The physiological disturbance during exposure to seawater (33 ppt) is greater at high temperatures (>14°C) compared to intermediate temperatures (10°C), and low temperatures (<7°C) may lead to a prolonged period of osmotic stress and increased mortality (Sigholt and Finstad 1990; Handeland et al. 2000). For intermediate water temperatures (which are best for welfare) transfer of salmon to full strength seawater (≈ 33 ppt) before the smoltification process has completed results in high mortality (>40%) and stunted growth rates for a period of 1 to 2 months (Duston 1994). Parr (not smoltified salmon) transferred to more brackish water of 20 ppt have less elevated/reduced mortality rates (<10%) and only temporarily stunted growth rates, while little to no mortality is observed below 10 ppt (Bjerknes 1992; Duston 1994). For

Slettet: M

Slettet:

Slettet: However, p

Merknad [BM8]: MB: Compared to what: to full strength sea water or compared to not being transferred?

Formatert: Engelsk (Storbritannia)

fully smoltified fish there is little effect of salinity on growth rate [?]/difference in growth rate pending salinity and no mortality (Duston 1994).

Fin condition

Fin erosion refers to damage to, and loss of, the tissue of the rayed fins (Latremouille, 2003) and is often found in farmed salmonids. Being externally visible, fin damage represent an intuitive and meaningful welfare indicator easily recognized by farmers and informed consumers (Ellis et al., 2008). While most studies on nociception in fish have focused on the head region or the body, Chervova (1997) demonstrated experimentally that fish fins are capable of nociception. Being live tissue capable of nociception the potential that mechanical injury to fin tissue is associated with pain seems probable. In some cases, mechanical fin damage may reflect aggressive behaviour within the rearing unit. Damage to the fins of salmonids is, however, more often caused by chronic infection with biofilm forming bacteria that progressively necrotise the fin edges (Berg 1948, Bernardet et al. 1996), similarly to leprosy in humans not necessarily being painful (insert reference). Except for grave cases, fin erosion in salmon occurs without further symptoms or behavioural changes. The fins fulfil important functions in both locomotion and intraspecific communication in salmonids (Pelis and McCormick, 2003; Abbot and Dill, 1985) and severe fin erosion thus has the potential to affect behaviour. However, the evidences are scarce or contradictory and any functional impairment following fin erosion has yet to be demonstrated scientifically. The breakdown of the epithelial barrier during active fin erosion may disrupt osmotic homeostasis and can thus cause severe stress on the fish (Clayton et al., 1998)..

Skin condition

The integrity of the skin-scale complex provides a relatively impermeable barrier to water and electrolytes. Epidermal damage such as scale loss, wounds and ulcers can therefore result in loss of body water and changed ion balance, and produces an osmotic stress that potentially can be life threatening (Bouck and Smith, 1979). There is evidence that ulceration of as little as 10% of the body surface area can result in high acute mortality and that the degree of mortality is directly related to the amount of skin damage (Bouck and Smith, 1979). Sub lethal skin damage might affect fish energetic due to increased metabolic cost involved in wound repair and osmoregulatory perturbations. Such chronic effects can affect growth rates and fecundity negatively; it may also lead to an increased susceptibility to other diseases (Noga, 2000). Many situations or management procedures in salmon aquaculture are associated with a high risk for mechanical damage to the skin. Examples are transport, sorting, vaccination, pumping, strong currents and high densities of fish, jelly fish burns, viral- and parasitic infections (Tunsjø, 2009). Virus- or bacterial infections often constitute the underlying cause of skin necrosis or ulcerations in fish. In sea farmed Atlantic salmon several infections are associated with severe or even pathognomic cutaneous symptoms, i.e. Winter Ulcer disease (infection with *Moritella viscosa*; Lunder et al. 1995, Benediktsdottir et al. 2000), atypical furunculosis (atypical *Aeromonas salmonida* infections; Wicklund and Dalsgaard 1998) and Pisciricekttsiosis (Mauel and Miller 2002). Several bacteria in the class Flexibacteriae often cause skin lesions and fin erosion in freshwater or seawater reared fish (Bernardet, 1998; Lorenzen, 1999) and it been shown that many fish pathogenic bacteria

Formatert: Engelsk (Storbritannia)

Merknad [BM9]: MB: Aslo there is a lot of research in other farm animals on skin lesions, where it is frequently used as welfare indicator, e.g. in WQ. Perhaps it is good to mention this. (i.e. add some more comparisons to welfare assessment in other farm animals, and also where this is not so much the case, as eg in maturation and smoltification, and boyancy, those things that are specific for fish/salmon. For example at the para on maturation I was tempted to comment that a little more about exactly how this para affects welfare would be helpful (where e.g. reduced growth rates may not be immediately related to reduced welfare because this is a natural process (and wheras in our modelling we normally take reduced growth to mean reduced welfare, but shouldn't do so here), etc [but I also understand priority should now be given to submitting the paper]

Slettet: Fin erosion refers to damage to, and loss of, the fin tissue of the rayed fins of teleost fish (Latremouille, 2003). This

Slettet: and

Slettet: is commonly found in farmed salmonids. While a thorough understanding of fin erosion and its treatment or prevention still is lacking there are

Slettet: is

Slettet: , however, sufficient data to justify fin erosion as a significant fish welfare indicator/issue (Ellis et al., 2008). Being an externally visible injury, fi ... [3]

Formatert: Engelsk (Storbritannia)

Slettet: the potential

Slettet: that fin erosion is associat ... [4]

Slettet: becomes very probable

Slettet: . The fins fulfil important ... [5]

Slettet: it is therefore likely that

Slettet: fin erosion and thus poor f ... [6]

Slettet: , therefore, impair

Slettet: have the potential to

Slettet: affect

Slettet: behaviour. However,

Slettet: the

Slettet: evidence

Slettet: s

Slettet: is

Slettet: are

Slettet: scarce or contradictory and

Slettet: any

Slettet: functional impairment foll ... [7]

Slettet: on

Slettet: the fish (Clayton et al., 19 ... [8]

Formatert: Engelsk (Storbritannia)

secrete proteolytic enzymes that participate in causing massive tissue damage and consequently contribute to the invasion of the pathogen (Leung & Stevenson 1988; Ostland et al., 2000). It should also be mentioned that epidermal damage provides access for infectious agents as wounds and non-intact mucus layers represent invasion routes for bacteria (Svendsen and Bøgwald, 1997).

Final model

After the selected welfare indicators, have been divided into levels and the levels ranked and weighted based on a review of the available litterature they are put together into an overall wellfare assessment modell.

the relative weighting factors (RWFs), indicator welfare scores (IWSs) and the overall welfare score (OWS) for the salmon in a specific sea cage are calculated as:

$$\mathrm{RWF}_i = \mathrm{WF}_i \cdot \left(\sum_{j=1}^{m} \mathrm{WF}_j \right)^{-1} \qquad (3)$$

$$\mathrm{IWS}_{i,seacgae} = \mathrm{IS}_{i,seacage} \cdot \mathrm{RWF}_i \qquad (4)$$

$$\mathrm{OWS}_{seacage} = \sum_{j=1}^{m} \mathrm{IWS}_{j,seacage} \qquad (5)$$

where m is the total number of indicators in the model and RWF_i, $\mathrm{IWS}_{i,seacage}$ and $\mathrm{IS}_{i,seacage}$ are the scores for the given sea cage for the i-th welfare indicator. A special case is made up of welfare indicator levels that are so detrimental for welfare that welfare is poor (minimum), no matter which levels are selected for the other indicators. These levels are called knockout levels, and if present OWS is defined as 0. Knockout levels are not included when calculating WFs, RWFs, ISs and IWSs.

Water temperature (°C)

Atlantic salmon have Positive performance and Preference for temperatures in the range 7-17 °C. These are temperatures within the normal seasonal range Atlantic salmon experience in sea cages. Very high (≥18°C) and low temperatures (≤2°C) are associated with Avoidance and Negative performance. Very high and low temperatures can also be lethal if they persist for a long time (knockout). We suggest dividing the Temperature welfare indicator (WI) into four levels (Table 4) and based on the weighting categories of the best and worst (not knockout) level we calculated a weighting factor (WF) of 8 (Table 5).

Salinity (ppt)

There is little evidence that salinity levels have significant effects on the welfare of adult Atlantic salmon. Some studies do, however, indicate that small, newly seawater transferred salmon may show a Preference to brackish water, perhaps to avoid sea lice or to regulate osmotic balance. Furthermore, sexually mature salmon may have impaired osmoregulatory capacity. In a sea cage containing 10-100,000 fish it is likely that some fish, for one or more of the above reasons, have compromised osmotic balance. For these fish the inability to have access to brackish water may lead to Negative performance and Reduced survival. We

Slettet: The integrity of the skin- ... [9]
Slettet: complex
Slettet: provide
Slettet: s
Slettet: a relatively impermeab ... [10]
Slettet: s
Slettet: an osmotic stress that
Slettet: potentially
Slettet: can be life threatening (... [11]
Slettet: There is evidence that
Slettet: U
Slettet: u
Slettet: lceration of as little as 1 ... [12]
Slettet: that
Slettet: the degree of mortality ... [13]
Slettet: is
Slettet: directly related to the a ... [14]
Slettet:
Slettet: lethal skin damage, eve ... [15]
Slettet: energetic
Slettet: due to increased metab ... [16]
Slettet: ; it
Slettet: may
Slettet: also
Slettet: lead to an increased dis ... [17]
Slettet: to other diseases
Slettet: (Noga, 2000). Furtherm ... [18]
Slettet: does
Slettet: in itself provides access ... [19]
Slettet: be the underlying
Slettet: cause
Slettet: of
Slettet: skin damages in fish. Se ... [20]
Slettet: the development of
Slettet: skin lesions and fin eros ... [21]
Slettet: has it been shown that
Slettet: many pathogenic fish b ... [22]
Slettet: participate in
Slettet: cause
Slettet: ing
Slettet: massive tissue damage ... [23]
Slettet: the
Slettet: pathogens (Leung & St ... [24]
Slettet: are
Slettet: transport, sorting, vacc ... [25]
Slettet: be caused by
Slettet: non-mechanical measu ... [26]
Merknad [BM10]: MB: Is rathe ... [27]
Slettet: term
Formatert ... [28]
Merknad [BM11]: MB: Delete? ... [29]
Formatert ... [30]
Merknad [t12]: TT: Unfortunat ... [31]
Formatert ... [32]
Slettet: for …hat salinity levels h ... [33]

suggest two levels for the Salinity WI (Table 4). In accordance with limited evidence for a strong effect on fish welfare the calculated WF is only 3 (Table 5).

Dissolved oxygen (%)

Oxygen levels above 80% do not cause welfare problems for salmon in sea cages and are associated with Positive performance. Below 80% a gradual increase in Negative performance and Survival may be observed, especially if the water temperature is high. We divided the Dissolved oxygen (DO) WI into four levels (Table 4), (including/excluding 1 knockout level). Its weighting factor (WF) is 9 (Table 5).

Water current (BL s^{-1})

The water flow through sea cages must be sufficient to secure replenishment of oxygen. While saturation with oxygen per se is a separate welfare indicator, water currents also affect swimming speeds of the fish. At moderate levels these may be positive for welfare (provide 'exercise'), but at higher values welfare may be reduced, andwhen the water velocity is so high that it exceeds critical swimming speed (U_{crit}) then water flow may even be lethal for the fish (knock-out). From the literature salmon appear to be able to maintain Natural behaviour up to about 0.6 BL s^{-1}. We were not able to find any literature about swimming speeds between the comfort zone and the U_{crit}s (pending size), but it is reasonable to assume that forced swimming leads to loss of control and hence Frustration over time. It is also reasonable to assume that U_{crit} in addition to size depend on the state of the fish, for instance how adapted it is to high water currents. The farmer must, in other words, know the ability of the fish or use an U_{crit} of 1.3 for safe margins. We suggest dividing the Water current WI into three levels (Table 4) with a WF of 3 (Table 5).

Stocking density (kg m^{-3})

Although the literature shows that salmon may congregate at extreme densities, it seems clear that high overall densities limit the fish's freedom to move in the cage. Stocking densities below 22 kg m^{-3} have been suggested to be optimal, and at higher densities welfare becomes incrementally worse until above 32 kg m^{-1}, where there is a substantial effect on Negative performance, Pain and Illness. We divided the Stocking density WI into four levels from <22 kg m^{-3} to above 32 kg m^{-3} (Table 4) and calculated a WF of 5 (Table 5).

Artificial lights

Atlantic salmon show photo-regulatory behaviour by vertical positioning in sea cages, and thus a Preference for positioning according to the depth of subsurface illumination. With narrow illumination of the cage volume (suboptimal), such as artificial lights positioned at only a shallow depth or above the surface, the salmon may be forced to school at high densities near the surface at night time and experience Frustration and Avoidance as other depth layers are not used. Artificial lights at multiple depths (optimal) or natural daytime light conditions allow the salmon to utilise the entire water column and hence contribute to Positive performance. Artificial lights can, therefore, be divided into three levels: optimal use (consisting of multiple lamps positioned at multiple depths to secure illumination of the preferred depth in stratified waters), sub-optimal use (not sufficiently covering the preferred

Slettet: welfare indicator
Slettet: Since the
Slettet: is relative poor
Slettet: becomes
Slettet: 3
Slettet: create
Slettet: is
Slettet: there is
Slettet: suggest
Slettet: ing
Slettet: welfare indicator
Slettet: and based on the weighting categories of the best and worst (not knockout) level we calculated a
Slettet: of
Merknad [f13]: I suggest you include a positive WF as well due to exercise and when velocity is <0.03 m/s little flushing is valid. Exercise will be at 0.2 to 0.6 FL/sec?. MB: seems a valid suggestion
Formatert: Engelsk (Storbritannia)
Slettet: e.g. if
Slettet: it seems clear that
Slettet: are
Slettet: welfare indicator
Slettet:
Slettet: therefore suggest to
Slettet: welfare indicator
Slettet: y
Slettet: , which may lead to
Slettet: an
Slettet: preferred
Slettet: is
Slettet: from
Slettet: ; by
Slettet: ,
Slettet: ; by

volume), and worst level (lack of artificial illumination when it should be applied in order to prevent sexual maturation at a later stage; see Table 4). This WI has a WF of 6 (Table 5).

Disturbances

Severe disturbances such as pumping of the fish may lead to Abnormal behaviour, Negative performance, Illness and Reduced survival. Moderate disturbances as crowding and topical delousing affect welfare to a lesser extent. It is also likely that light disturbances (activity around the cage) may stress the fish to some extent, and that no disturbances promote Natural or normal cage behaviour. We, therefore, propose to divide the Disturbances WI into four levels from non to severe disturbance and calculate a WF of 8.

Daily mortality rate (% day^{-1})

High daily mortality compared to benchmark is indicative of Illness, Reduced survival and Negative performance (prior to death of diseased fish), while low daily mortality indicates Positive performance. Based on the mortality benchmark study we suggest to divide the Daily mortality WI into five levels from best (at or below the 10-percentile curve) to worst (at or above 90-percentile curve, Table 4) and calculated a WF of 16 (Table 5). Long term values at or above 90-percentile will lead to extreme mortality (which, accordingly, is considered a knockout level). [MB: Insert WF]

Feed conversion ratio

An expected or less than expected FCR is indicative of Positive performance, while increased FCR is indicative of Negative performance and Illness. Based on the values postulated by the experts FCR can be divided into levels from best (at or below expected FCR) to worst (increased FCR by more than 0.22, Table 4) and a WF of 6 (Table 5).

Appetite

Prolonged (weeks to months) poor appetite is clearly indicative of Negative performance and Illness, and good appetite suggests Positive performance. For practical application in SWIM 1.0, we suggest dividing the Appetite WI intro three levels (Table 4) with a WF of 3 (Table 5).

Disease

Paul

Sea lice

Infestations of more than 0.75 lice g^{-1} fish are lethal for the fish (knockout), at lower levels >0.5 lice g^{-1} fish may suffer from Disease, Pain, Reduced survival and Negative performance (Table 5). We specified five levels for the Sea lice WI, from No lice as best level (Positive performance), via light infestation (only Copepodid and Chalimus stages and/or <0.05 lice g^{-1} fish for the pre-adult and adult stages), to >0.5 adult or pre-adult lice g^{-1} fish (Table 4). Based on this information the indicator gets a WF of 10 (Table 5).

Condition factor

Salmon with a condition factor between 1.0 and 1.5 have lipid reserves (Positive performance), while salmon with a condition factor between 0.9 and 1.0 have little lipid

Slettet: ,
Slettet: ;
Slettet: (
Slettet: gives
Slettet: a limited
Slettet: welfare indicator
Slettet: welfare indicator
Slettet: (
Slettet: postulated
Slettet: from
Slettet:) (
Slettet: It is clear that p
Slettet: that
Slettet: welfare indicator
Slettet: and
Slettet: lead to
Slettet: suggest to
Slettet: y
Slettet: welfare indicator
Merknad [BM14]: MB Already said in first sentence of this paragraph.
Slettet: In addition to these four levels, we have also specified a lethal knock
Formatert: Engelsk (Storbritannia)
Slettet: -out level.
Slettet: from
Slettet: to

reserves (Negative performance). Extreme condition factors (>1.6) may be indicative of malformation and hence Negative performance. We divided the Condition factor WI into three levels (Table 4) with a WF of 4.

Emaciated fish

Emaciated fish show Abnormal behaviour, Negative performance, strongly Reduced survival and are likely to be Ill and experience Pain. A positive identification of an emaciated fish is therefore a knockout for that individual fish, while potentially emaciated fish (fish showing signs of becoming emaciated) most probably also have Reduced survival, experience Illness and Pain, while non-emaciated fish are presumed to be healthy (Positive performance). We suggest dividing the Emaciated fish WI into three levels (Table 4) with a WF of 16 (Table 5).

Maturation

Mature females have invested heavily in development of gonads and show Negative performance and strongly Reduced survival. Mature males and especially mature juvenile males invested less. This gives four indicator levels from best (Not mature) to worst (Mature female) (Table 4) and a WF of 7 (Table 5).

Smoltification

Fully smoltified fish have little problems with osmoregulation in full strength seawater (Positve performance). Impaired smolts have Negative performance and Reduced survival, especially at high and low temperatures. This gives WI levels from worst (incomplete smoltification at high temperature, >20 °C) to best (fully smoltified) (Table 4) and a WF of 9 (Table 5).

Fin condition

Fin erosion represents injury to live tissue with the potential for inflammation and Pain. Damaged epithelial structures may also represent invasion routes for pathogens and thus lead to Illness, and reduced Performance. Furthermore, damaged fin tissue, especially on the dorsal fin, may reflect high levels of Aggression in the rearing unit. The Fin condition WI is divided into four levels ranging from normal healthy fins without tissue loss to severely damaged fins with tissue loss, that also may be suffering from necrosis, inflammation, bleeding or exposed fin rays (Table 4). The WF calculated in SWIM 1.0 is 18 (Table 5).

Skin condition

Similar to the Fin condition WI damages to the skin may cause Pain and represent invasion routes for pathogens leading to infection and Illness and possibly reduced Survival in salmon. Even smaller skin damages may lead to long term Negative performance due to increased metabolic cost involved in wound repair and osmoregulatory perturbations. Both the size of the affected area and the depth (whether it is penetrating or superficial) of skin damages will probably contribute to the severity of the condition. Thus, the indicator is divided into five levels (Table 4) ranging from normal healthy skin to penetrating and/or multiple wounds or ulcers that also may be infected. Its WF is 17 (Table 5).

Table 4: Welfare indicators (WI) with their levels from best to worst and weighting factor (WF). IS=Indicator level score; K: knock-out (i.e. level that results in poor welfare regardless of other model WI's). Individual fish parameters are given for individually sampled fish. In a sample of 20 fish, each fish counts for 5% of the sampled population. The final result is a distribution of welfare scores for whole group of fish in the sea cage in question.

		Welfare indicator		Levels	IS
Environment	Sea cage	Temperature(°C)	1	7-17	1.00
			2	2-7	0.50
			3	≤2, ≥18 short term	0.00
			4	≤2, ≥18 long term	K
		Salinity(ppt)	1	Access to brackish water	1.00
			2	No access to brackish water	0.00
		Oxygen(%),	1	>80%, all temperatures	1.00
			2	70-80% for warm water (≈18°C), 60-80% (≈12°C), 50-80% cold water (6°C)	0.50
			3	60-70% for warm water (≈18°C), 40-60% (≈12°C), 30-50% cold water (6°C)	0.00
			4	<60% for warm water (≈18°C), <40% (≈12°C), <50% cold water (6°C)	K
		Water current (BL s^{-1})	1	<0.6 BL s^{-1}	1.00
			2	0.6 – U_{crit},	0.00
			3	≥U_{crit}	K
		Stocking density (kg m^{-3})	1	<22	1.00
			2	22-26	0.66
			3	26-32	0.33
			4	>32	0.00
		Artificial lights	1	Optimal	1.00
			2	Suboptimal	0.50
			3	Lack of illumination when required	0.00
		Disturbances	1	Severe	1.00
			2	Moderate	0.66
			3	Light	0.33
			4	None	0.00
Animal		Mortality (% day^{-1})	1	At or below 10 percentile curve	1.00
			2	Below benchmark curve	0.75
			3	At the benchmark curve	0.50
			4	Above the benchmark curve	0.25
			5	At or above the 90 percentile curve	0.00
			6	At or above the 90 percentile curve, long term	K
		Feed conversion ratio	1	As expected or less	1.00
			2	Increased, between 0.05-12	0.66
			3	Increased, between 0.12-0.22	0.33
			4	Increased, >0.22	0.00
		Appetite	1	Good appetite	1.00
			2	As expected	0.50
			3	Poor appetite	0.00
		Disease	1	Paul	1.00
			2		0.50
			3		0.00
	Individual fish	Sea lice	1	No lice	1.00
			2	Light infestation	0.66
			3	>0.10 pre-adult or adult lice g^{-1} fish	0.33
			4	>0.50 pre-adult or adult lice g^{-1} fish	0.00
			5	>0.75 pre-adult or adult lice g^{-1} fish	K
		Condition factor	1	1.0-1.5	1.00
			2	0.9-1.0, >1.6	0.50
			3	<0.9	0.00
		Emaciated fish	1	No	1.00
			2	Potential	0.00
			3	Yes	K
		Maturation	1	Not mature	1.00
			2	Precocious male	0.66
			3	Mature male	0.33

Merknad [LHS15]: Shall we divide both table 4 and 5 into two. For each; one for Sea cage WIs and one for Individual fish WIs? MB: No, let's do that in later versions of the model.

Merknad [BM16]: MB: Is missing?

Formatert: Engelsk (Storbritannia)

Slettet: Parameters

Slettet: ,

Formatert: Engelsk (Storbritannia)

Slettet: means

Merknad [BM17]: MB: ? This needs more discussion.

Formatert: Engelsk (Storbritannia)

Slettet:

Slettet:

Merknad [BM18]: MB: Then present in ppt (or leave out)

Formatert: Engelsk (Storbritannia)

Merknad [BM19]: MB: Paul is the best level!

Formatert: Engelsk (Storbritannia)

Slettet: state

	4	Mature female	0.00
Smoltification	1	Fully smoltified	1.00
	2	Parr, access to brackish water	0.80
	3	Parr, incomplete smoltification, 10°C	0.60
	4	Parr, incomplete smoltification, 14°C	0.40
	5	Parr, incomplete smoltification, 7°C	0.20
	6	Parr, incomplete smoltification, 20°C	K
Fin condition	1	Normal healthy fins, nothing to comment	1.00
	2	Scar tissue or slight necrosis	0.66
	3	Moderate current skin damage and/or necrosis including splitting and/or thickening	0.33
	4	Severe skin damage and/or necrosis with bleeding and/or inflammation and/or exposed fin rays and severe tissue loss	0.00
Skin condition	1	Normal healthy skin, nothing to comment	1.00
	2	Scar tissue, healed	0.80
	3	Scale loss (dislocated or missing scales)	0.60
	4	Superficial wound or ulcer < 1 cm^2	0.40
	5	Superficial wound or ulcer > 1 cm2	0.20
	6	Penetrating and/or multiple wounds or ulcers possibly infected	0.00

Slettet: state

Merknad [BM20]: MB: Add lines in table?

Formatert: Engelsk (Storbritannia)

	Welfare indicator	Best level	Weighting categories	Max WS_{wcl}	Worst level	Weighting categories	Min WS_{wcl}	WF	RWF
Sea cage	Temperature	7-17°C	Positive performance Preference	3 1	≤2, ≥18 short term	Avoidance Negative performance	-1 -3	8	
	Salinity	Access to brackish water	Preference	1	Not access to brackish water	Negative performance Reduced survival	-1 -1	3	
	Oxygen	100%	Positive performance	1	60-70% for warm water (≈18°C), 40-60% (≈12°C), 30-50% cold water (6°C)	Negative performance Reduced survival	-3 -5	9	
	Water current	<0.6 BL s^{-1}	Natural behaviour	1	>0.6 BL s^{-1}	Frustration	-2	3	
	Stocking density	<22 kg m^{-3}	Natural behaviour	1	>32 kg m^{-3}	Neg. performance Pain Illness	-2 -1 -1	4	
	Artificial lights	At multiple depths	Preference Positive performance	1 1	Lack of illumination when required	Frustration Avoidance Negative performance	-1 -1 -2	6	
	Disturbances	None	Natural behaviour	1	Severe	Abnormal behaviour Negative performance Illness Reduced survival	-3 -2 -1 -1	8	
	Daily mortality	At or below 10-percentile	Positive performance	3	At or above 90-percentile	Negative performance Illness Reduced survival	-3 -5 -5	16	
	FCR	As expected or less	Positive performance	1	Increased by more than 0.22	Negative performance Illness	-2 -3	6	
	Appetite	Poor appetie	Positive performance	1	Good appetite	Negative performance Illness	-2 -3	6	
	Disease								
Individual fish	Sea lice	No lice	Positive performance	1	Preaduly and adult stages; >0.50 lice g^{-1} fish	Illness Pain Reduced survival Negative performance	-3 -1 -3 -2	10	
	Condition factor	1.1-1.5	Positive performance	3	<0.9	Negative performance	-2	5	
	Emaciated fish	No	Positive performance	1	Potential	Abnormal behaviour Negative performance Reduced survival Illness Pain	-3 -3 -3 -3 -3	16	

Merknad [BM21]: MB: This table is superfluous (explained in text; delete (and add WS in first part of table, and you may include the WS-wcl into the text as well, if you like.

Formatert: Engelsk (Storbritannia)

	Maturity state	Mature female	Negative performance Reduced survival	-2 -1	Not mature	Positive performance	1	4	
	Smoltification state	Fully smoltified	Positive performance	1	Parr at 20 °C	Negative performance Reduced survival	-3 -5	9	
	Fin condition	Normal healthy fins, nothing to comment	Positive performance	3	Severe skin damage and/or necrosis with bleeding and/or inflammation and/or exposed fin rays and severe tissue loss	Negative performance Aggression Pain Illness	-3 -2 -5 -5	18	
	Skin condition	Normal healthy skin, nothing to comment	Positive performance	1	Penetrating and/or multiple wounds or ulcers possibly infected	Negative performance Pain Illness Reduced survival	-3 -3 -5 -5	17	

Table 5: Weighting procedure

Discussion

Methodology

The objectives of this paper were to review basic welfare indicators of sea-cage farmed Atlantic salmon and to generate a semantic model (SWIM 1.0) to enable farmers to assess overall welfare. Although there are many papers published on semantic modelling and on welfare assessment in various species of farm animals, this is the first time systematic review of scientific statements has been performed and presented on farmed fish. This secures full transparency. A main advantage of reviewing welfare indicators according to the principles of semantic modelling was that it gave focus to the review, it was necessary to assess each indicator in terms of what the indicator in itself said about animal welfare. The prevented long and overlapping essays about each indicator; special cases, interactions which are an inherent part of a complex problem area such as fish welfare in sea cages.

In order to create an overall WI model it is necessary to reduce complexity. The advantage of transparency in semantic modelling is that it shows where these reductions are made and where there is scope for further upgrading with new scientific knowledge. Semantic modelling also supports transparency of the model itself, allowing criticism of underlying principles and specific choices made. This facilitates updating the model also when other parties would disagree with some of the choices.

The semantic-modelling procedure used in SWIM 1.0 was derived from Bracke et al. (2002a) and De Mol et al. (2006). It started with an extensive literature review for statements that are somehow relevant for the welfare of Atlantic salmon farmed in sea cages. This ensures that the formulation of WI levels and the calculatoin of WFs is done in relation to unbiased scientific statements, i.e. statements that have not been produced in order to generate preconceived notions of how welfare should be assessed.

A major criticism of semantic modelling is that it is subjective; one has to decide on how to divide the indicators into levels, which weighting categories are appropriate for each indicator and one must assign indicator scores and weighting scores. These decisions are indeed based on a subjective interpretation of the meaning of the collected scientific information. This subjectivity is, however, expected to decrease with increasing quality and amount of available scientific information and refinement of procedures. This will reduce freedom of interpretation of the data. Another point is that the information in the model and the semantic-modelling procedure are objective, i.e. the information is scientifically valid and the semantic-modelling procedure is formalised and has been described in detail elsewhere (Bracke et al., 2002a; 2008ab; Bracke 2011). It is designed to take the modeller's point of view, as much as possible, out of the equation (Bracke et al., 2002a; Bracke, 2008ab).

The model

This is the first time semantic modelling has been used to create OWA for fish and, although, there are several risk assessment schemas for fish farming, there are to our knowledge no schemas for assessing fish welfare. As the SWIM 1.0 model is based on the literature, including the mentioned risk assessment schemas, it would be a circular argument to compare

Slettet: Model judgement and future perspectives
Slettet: n
Slettet: model for use by farmers using semantic modelling
Slettet: of different farmed animal scenarios
Slettet: the statements
Slettet: is included in the publication itself
Slettet: Otherwise it would have been very easy to fall into
Slettet: be able to
Slettet: welfare indicator
Slettet: the
Slettet: of
Slettet: becomes very clear
Slettet: provides
Slettet: whenever sufficient
Slettet: becomes available to do so
Slettet: the
Slettet: final
Slettet: makes it easy to
Slettet: e
Slettet: not only when new scien ... [34]
Slettet: interested
Slettet: who may
Merknad [BM22]: MB: repetitious
Formatert: Engelsk (Storbritannia)
Slettet: One of the main advanta ... [35]
Formatert: Engelsk (Storbritannia)
Slettet: i
Slettet: s
Slettet: , using the criterion that t ... [36]
Slettet: are
Slettet: animal and farm situatior ... [37]
Slettet: later
Slettet: indicator
Slettet: weighting
Slettet: collected
Slettet: explain
Slettet: the
Slettet: model should be
Slettet: Good information allows for less
Slettet: ,
Slettet: ; and
Formatert: Engelsk (Storbritannia)
Slettet: I

the model with the risk assessment schemas. It is, however, commonly agreed that daily mortality is probably one of most important WI's/welfare indicators for the fish in a sea cage and that salinity probably is one of the least important ones. Based on our expertise, we, propose/believe that the scoring in SWIM 1.0 has a sufficient validity for fish farmers to start using the model. That said, however, it is anticipated that the model will be in need of further upgrading. It is also important to note that although the SWIM 1.0 model gives an OWA index as output, its main purpose is its use as a diagnostic tool to identify indicators that can be used to improve welfare. Finally, we intend to test SWIM 1.0at several sites, and further improve its levels and weighting rules.

Example site(s)

Necessary?

Acknowledgements

SWIM is part of the RCN and FHF funded project 199728 SALMOWA.

References

Abbott, J.C., Dill, L.M., 1985. Patterns of aggressive attack in juvenile steelhead trout (Salmo-gairdneri). Can. J. Fish. Aquat. Sci. 42, 1702-1706.

Adams, C., Huntingford, F., Turnbull, J., Arnott, S., Bell, A., 2000. Size heterogeneity can reduce aggression and promote growth in atlantic salmon parr. Aquaculture International 8: 543-549.

Adams, C.E, Turnbull, J.F., Bell, A., Bron, J.E., Huntingford, F.A. 2007. Multiple determinants of welfare in farmed fish, stocking density, disturbance, and aggression in Atlantic salmon (Salmo salar). Can. J. Fish Aquat. : 336-344

Alne, H., Thomassen, M.S., Takle, H., Terjesen, B.F., Grammes, F., Oehme, M., Refstie, S., Sigholt, T., Bergen, R.K., Rørvik,K.-A., 2009. Increased survival by feeding tetradecylthioacetic acid during a natural outbreak of heart and skeletal muscle inflammation in S0 Atlantic salmon, Salmo salar L.. Journal of Fish Diseases 11: 953-961

Anon. 2001. Scientists‟ assessment of the impact of housing and management on animal welfare. Journal of Appl. Animal Welfare Science 4: 3-52.

Anon, 2009.(In Norwegian) Formler og beregninger. In: Fôring i dybden. Anon. (ed). Skretting, Norway, pp. 21-25.

Anon, 2011. Supersmolt reduserer "pinne-forekomst" hos ørret (in Norwegian). Europharma nyhetsbrev 25.

Ashley, P.A. 2007. Fish welfare: Current issues in aquaculture. Applied animal behaviour science 104: 199-235

Aunsmo, A., Bruheim, T., Sandberg, M., Skjerve, E., Romstad, S., Larssen, R. B., 2008. Methods for investigating patterns of mortality and quantifying cause-specific mortality in sea-farmed Atlantic salmon *Salmo salar*. Diseases of Aquatic organisms 81: 99-107

Slettet: easy to agree
Slettet: the
Slettet: significant
Slettet: ss
Slettet: W
Slettet: therefore
Slettet: degree of
Slettet: and that
Slettet: can
Slettet: here
Slettet: they remember that
Slettet: as output
Slettet: the
Slettet: of the model
Slettet: which
Slettet: have contributed negatively to OWA index
Slettet: hope to be able to follow up
Slettet: , by testing the model
Merknad [BM23]: Also based on experiences from farmers directly?
Slettet: if necessary adjust some of the
Formatert: Engelsk (Storbritannia)
Formatert: Engelsk (Storbritannia)
Formatert: Engelsk (Storbritannia)
Formatert: Engelsk (Storbritannia)

Aunsmo, A., Valle, P. S., Sandberg, M., Midtlyng, P., Bruheim, T. 2010. Stochastic modelling of direct costs of pancreas disease (PD) in Norwegian farmed Atlantic salmon (Salmo salar L.) . Preventive Veterinary Medicine 93: 233-241

Austreng, E., Storebakken, T. and Åsgård, T. 1987. Growth rate estimates for cultured Atlantic salmon and rainbow trout. Aquaculture, 60: 157-160.

Bakke, H., Bjerknes, V., Øvreeide, A., 1991. Effects of rapid changes in salinity on the osmoregulation of postsmolt Atlantic salmon (Salmo salar). Aquaculture 96, 375-382

Beitinger, T. L. 1990. Behavioral reactions for the assessment of stress in fishes. J. Great Lakes Res. 16: 495-528

Berg, A. J., Sigholt, T., Seland, A., Danielsberg, A. 1996. Effect of stocking density, oxygen level, light regime and swimming velocity on the incidence of sexual maturation in adult Atlantic salmon (Saho salar 1. Aquaculture 143: 43-59

Berg, A., Rødseth, O. M., Tangerås, A., Hansen, T., 2006. Time of vaccination influences development of adhesions, growth and spinal deformities in Atlantic salmon *Salmo salar*. Diseases of aquatic organisms 69: 239-248

Bergheim, A., Gausen, M., Naess, A., Holland, P.M., Krogedal, P., Crampton, V., 2006. A newly developed oxygen injection system for cage farms. AQUACULT ENG 34, 40-46.

Bernardet, J.F., 1998. Cytophaga, Flavobacterium, Flexibacter and Chryseobacterium infections in cultured marine fish. Fish Pathol. 33, 229-238.

Berridge, K.C., 2004. Motivation concepts in behavioral neuroscience. Physiology & Behavior 81: 179-209

Bjerknes, V., Duston, J., Knox, D., Harmon, P. 1992. Importance of body size for acclimation of underyearling Atlantic salmon parr (*Salmo salar* L.) to seawater. Aquaculture 104: 357-366.

Björnsson, B.T., Taranger, G.L., Hansen, R., Stefansson, S.O., Haux, C., 1994. The Interrelation between Photoperiod, Growth Hormone, and Sexual Maturation of Adult Atlantic Salmon (*Salmo salar*). General and Comparative Endocrinology 93, 70-81

Bouck, G.R., Smith, S.D., 1979. Mortality of experimentally descaled smolts of coho salmon (*Oncorhynchus-kisutch*) in fresh and salt-water. Transactions of the American Fisheries Society. 108, 67-69.

Bolger, T., Conolly, P.L., 1989. The selection of suitable indices for the measurement and analysis of fish condition. Journal of Fish Biology 34: 171-182.

Bond, CE, 1996. Biology of Fishes, 2nd Edition. Saunders college publishing, Tokyo, 402-415.

Bowers, J. M., Mustafa, A., Speare, D. J., Conboy, G. A., Brimacombe, M., Sims, D. E., Burka, J. F. 2000. The physiological response of Atlantic salmon, Salmo salar L., to a single experimental challenge with sea lice, Lepeoptheirus salmonis. Journal of Fish Diseases 23: 165-172

Boxaspen, K. 2006. A review of the biology and genetics of sea lice. ICES Journal of Marine Science 63: 1304-1316

Braastad, B., Damsgård, B., Jarp, J., Juell, J.-E., Valle, P.S., Hjelt, K., Ruud, L.E., (Eds), 2005 Forskningsbehov innen dyrevelferd i Norge. Ministry of Agriculture and Food, Report, 27.04.2005

Formatert: Engelsk (Storbritannia)

Bracke, M.B.M., 2008. RICHPIG: a semantic model to assess enrichment materials for pigs. Animal Welfare 17, 289-304.

Bracke, M.B.M., 2011. Review of wallowing in pigs: Description of the behaviour and its motivational basis. Applied Animal Behaviour Science, published online, doi:10.1016/j.physletb.2003.10.071

Bracke, M.B.M., Spoolder, H.A.M., 2011. Review of wallowing in pigs: Implications for animal welfare. Animal Welfare 20:347-363.

Bracke, M.B.M., Spruijt, B.M., Metz, J.H.M., 1999a. Overall welfare assessment reviewed. Part 1: Is it possible? Netherlands Journal of Agricultural Science 47,279–291.

Bracke, M.B.M., Metz, J.H.M., Spruijt, B.M., 1999b. Overall welfare reviewed. Part 2: Assessment tables and schemes. Netherlands Journal of Agricultural Science 47, 293–305.

Bracke, M.B.M., Spruijt, B.M., Metz J.H.M., 1999c. Overall welfare reviewed. Part 3: Welfare assessment based on needs and supported by expert opinion. Netherlands Journal of Agricultural Science 47, 307–322.

Bracke, M.B.M., Spruijt, B.M., Metz, J.H.M., Schouten, W.G.P., 2002a. Decision support system for overall welfare assessment in pregnant sows. A: Model structure and weighting procedure. Journal of Animal Science 8, 1819–1834.

Bracke, M.B.M., Metz, J.H.M., Spruijt, B.M., Schouten, W.G.P., 2002b. Decision support system for overall welfare assessment in pregnant sows. B: Validation by expert opinion. Journal of Animal Science 8, 1835–1845

Bracke, M.B.M., Hulsegge, B., Keeling, L., Blokhuis, H.J., 2004a. Decision support system with semantic model to assess the risk of tail biting in pigs: 1. Modelling. Applied Animal Behaviour Science 87: 31-44.

Bracke, M.B.M., Hulsegge, B., Keeling, L., Blokhuis, H.J., 2004b. Decision support system with semantic model to assess the risk of tail biting in pigs: 2. „Validation". Applied Animal Behaviour Science 87: 45-54.

Bracke, M.B.M., Zonderland, J.J, Bleumer, E.J.B., 2007a. Expert judgement on enrichment materials for pigs validates preliminary RICHPIG model. Applied Animal Behaviour Science 104:1-13.

Bracke, MBM, Zonderland, JJ, Bleumer, EJB 2007b. Expert consultation on weighting factors of criteria for assessing environmental enrichment materials for pigs. Applied Animal Behaviour Science 104, 14–23.

Bracke, M. B. M., S. A. Edwards, J. H. M. Metz, J. P. T. M. Noordhuizen and B. Algers. 2008. Synthesis of semantic modelling and risk analysis methodology applied to animal welfare. Animal 2: 1061-1072)

Braithwaite, V.A., Huntingford, F.A., 2004. Fish and welfare: do fish have the capacity for pain perception and suffering? Animal Welfare 13:87-92.

Braithwaite, V. A., Boulcott, P., 2007. Pain perception, aversion and fear in fish. Diseases of aquatic organisms 75:131-138

Braithwaite, V.A., 2010. Do fish feel pain? Oxford University Press, Oxford, UK.

Bricknell, I.R., Dalesman, S.J., O'Shea, B., Pert, C.C., Luntz, A.J.M., 2006. Effect of environmental salinity on sea lice *Lepeophtheirus salmonis* settlement success. . Diseases of aquatic organisms 71:201-212

Formatert: Engelsk (Storbritannia)

Slettet: Bracke et al., 1999d.¶

Slettet: Bracke, M.B.M., 2008a. RICHPIG: a semantic model to assess enrichment materials for pigs. Animal Welfare 17, 289-304.¶

Slettet: b

Slettet: Bracke, M.B.M., 2011. Review of wallowing in pigs: Description of the behaviour and its motivational basis. Applied Animal Behaviour Science, published online, doi:10.1016/j.physletb.2003.10.071¶

Busacker, G.P., Adelman, I.R., Goolish, E.M., 1990. Growth. In: Schreck, C.B., Moyle, P.B. (Eds.), Methods for Fish Biology. American Fisheries Society, Bethesda, MD, pp. 363–387.

Chandroo, K.P., Duncan, I.J.H., Moccia, R.D., 2004a. Can fish suffer?: perspectives on sentience, pain, fear and stress. Applied Animal Behaviour Science 86(3-4): 225-250.

Chandroo, K.P., Yue, S., Moccia, R. D., 2004b. An evaluation of current perspectives on consciousness and pain in fishes. Fish and fisheries 5: 281-295

Chervova, L.S., 1997. Pain sensitivity and behaviour of fishes. J. Ichthyol 37, 106–111.

Clayton, R.D., Stevenson, T.L., Summerfelt, R.C., 1998. Fin erosion in intensively cultured walleyes and hybrid walleyes. Progress. Fish-Cult. 60, 114-118.

Coyne, R., Smith, P., Inger Dalsgaard, I., Nilsen, H., Kongshaug, H., Bergh, Ø., Samuelsen, O. 2006. Winter ulcer disease of post-smolt Atlantic salmon: An unsuitable case for treatment? . Aquaculture 1-4: 171-178

Crampton, V., Hølland, P.M., Bergheim, A., Gausen, M., Næss, A., 2003. Oxygen effects on caged salmon. Fish Farming Int. 26–27.

Damsgård, B. , Sørum, U. , Ugelstad, I. , Eliassen, R. A. and Mortensen, A., 2004. Effects of feeding regime on susceptibility of Atlantic salmon (Salmo salar) to coldwater vibriosis. Aquaculture 239, 37-46.

Damsgård, B., Juell, J-E., Braastad, B. O., 2006. Welfare in farmed fish. Report 5/2006, Fiskeriforskning, Norway

Davison, W., 1997. Training and its effects on teleost fish. Comp. Biochem. Physiol. 94, 1-10.

De Mol RM, Schouten WGP, Evers E, Drost WC, Houwers HWJ and Smits AC 2004. Integrale welzijnsbeoordeling leghennen. (Integrated welfare assessment laying hens). Report 239. Agrotechnology & Food Innovations of Wageningen University and Research Centre, Wageningen

De Mol, RM, Schouten, WGP, Evers, E, Drost, WC, Houwers, HWJ, Smits, AC 2006. A computer model for welfare assessment of husbandry systems for laying hens. Netherlands Journal of Agricultural Science 54, 57–168

Dempster, T., Juell, J.-E., Fosseidengen, J. E., Fredheim, A., Lader, P. 2008. Behaviour and growth of Atlantic salmon (Salmo salar L.) subjected to short-term submergence in commercial scale sea-cages. Aquaculture 276: 103-111

Dempster, T, Korsøen, Ø., Folkedal, O. Juell, J,-E., Oppdal, F. 2009. Submergence of Atlantic salmon (Salmo salar L.) in commercial scale sea-cages: A potential short-term solution to poor surface conditions. Aquaculture 288: 254-263

Deitch, E.J., Fletcher, G.L., Peterson, L.H., Costa,L.A.SF, Shears, M.A., Driedzic, W.R., Gamperl, A.K., 2006. Cardiorespiratory modifications, and. limitations, in post-smolt growth hormone transgenic Atlantic salmon (Salmo salar). The Journal of Experimental Biology 209, 1310-1325

Diggles, B. K., Cooke, S.J., Rose, J.D., Sawynok, W., 2011. Ecology and welfare of aquatic animals in wild capture fisheries. Reviews in Fish Biology and Fisheries, published online Doi: 10.1007/s11160-011-9206-x

Duston, J. 1994. Effect of salinity on survival and growth of Atlantic salmon (Salmo salar) parr and smolt. Aquaculture 121: 115-124

Formatert: Engelsk (Storbritannia)

Formatert: Engelsk (Storbritannia)

Formatert: Engelsk (Storbritannia)

Formatert: Engelsk (Storbritannia)

EFSA (European Food Safety Authority) 2006a. Scientific opinion on the risks of poor welfare in intensive calf farming systems. An update of the Scientific Veterinary Committee Report on the Welfare of Calves. EFSA-Q-2005-014. The EFSA Journal 366: 1-36.

EFSA (European Food Safety Authority) 2006b. Scientific report on the risks of poor welfare in intensive calf farming systems. An update of the Scientific Veterinary Committee Report on the Welfare of Calves. EFSA-Q-2005-014 (144 pp), Annex to EFSA (2006a).

EFSA, 2008. Animal welfare aspects of husbandry systems for farmed Atlantic salmon - Scientific Opinion of the Panel on Animal Health and Welfare. Annex to the EFSA Journal (2008) 736, 1-122.

EFSA, 2009. General approach to fish welfare and to the concept of sentience in fish The EFSA Journal (2009) 954, 9-27.

Einen, O., Waagan, B., Thomassen, M. S., 1998. Starvation prior to slaughter in Atlantic salmon (Salmo salar) I. Effects on weight loss, body shape, slaughter- and fillet-yield, proximate and fatty acid composition. Aquaculture 166: 85-104.

Einen, O., Mørkøre, T., Rørå, A.M.B., Thomassen, M. S., 1999. Feed ration prior to slaughter—a potential tool for managing product quality of Atlantic salmon (Salmo salar). Aquaculture 178: 149–169.

Ellis, T., Oidtmann, B., St-Hilaire, S., Turnbull, J., North, B., MacIntyre, C., Nikolaidis, J., Hoyle, I., Kestin, S. & Knowles T, 2008. Fin erosion in farmed fish. in: Branson, E. (Ed.). Blackwell, Oxford, pp. 121-149.

Endal, H.P et al. 2000. Effects of continous additional light on growth and sexual maturity in Atlantic salmon, reared in sea cages. Aquaculture 191: 337-349

Ersdal, C., Midtlyng, P.J., Jarp, J., 2001. An epidemiological study of cateracts in seawater farmed Atlantic salmon *Salmo salar*. Diseases of aquatic organisms 45, 229-236.

Farrel, A. P. 2005. Bulk oxygen uptake measured with over 60,000 kg of adult salmon during live-haul transportation at sea. Aquaculture : 646-652

Fernö, A., Huse, I., Juell, J.-E., Bjordal, Å., 1995. Vertical distribution of Atlantic salmon (*Salmo salar* L.) in net pens: trade-off between surface light avoidance and food attraction, Aquaculture 132, 285–296

Finstad, B., Bjørn, P. A., Grimnes, A., Hvidsten, N. A. 2000. Laboratory and field investigations of salmon lice (Lepeophtheirus salmonis Krøyer) infestation on Atlantic salmon (Salmo salar L.) postsmolts. Aquaculture Research 31: 795-803

Finstad, G., Bjørn, P.A., Todd, C.D., Whoriskey, F., Gargan, P. G., Forde, G., Revie, C.W. 2011. The Effect of Sea Lice on Atlantic Salmon and other Salmonid Species. In: Atlantic Salmon Ecology. Aas, Ø., Einum, S., Klemetsen, A., Skurdal, J. (Eds.). Blackwell Publishing Ltd, UK. pp 253-276

Fivelstad, S., Smith, M. J. 1991. The oxygen consumption rate of Atlantic salmon (Salmo salar L.) reared in a single pass landbased seawater system. Aquaculture Engineering 4: 227-235

Fjelldal, P.G., Hansen, T., Breck, O., Sandvik, R., Waagbo, R., Berg, A., Ornsrud, R., 2009a. Supplementation of dietary minerals during the early seawater phase increase vertebral strength and reduce the prevalence of vertebral deformities in fast-growing under-yearling Atlantic salmon (Salmo salar L.) smolt. Aquaculture Nutrition 15, 366-378.

Formatert: Engelsk (Storbritannia)

Formatert: Engelsk (Storbritannia)

Formatert: Engelsk (Storbritannia)

Formatert: Engelsk (Storbritannia)

Formatert: Engelsk (Storbritannia)

Formatert: Engelsk (Storbritannia)

Fjelldal, P.G., Glover, K.A., Skaala, O., Imsland, A., Hansen, T.J., 2009b. Vertebral body mineralization and deformities in cultured Atlantic salmon (Salmo salar L.): Effects of genetics and off-season smolt production. AQUACULTURE 296, 36-44.

Fleming, I. A., 1998. Pattern and variability in the breeding system of Atlantic salmon (Salmo salar), with comparisons to other salmonids. Canadian Journal of Fisheries and Aquatic Sciences 55: 59-76

Fleming, I. A., Einum, S., 2011. Reproductive Ecology: A Tale of Two Sexes. In: Atlantic Salmon Ecology. Aas, Ø., Einum, S., Klemetsen, A., Skurdal, J. (Eds.). Blackwell Publishing Ltd, UK. pp 33-65

Flood, M.J., John Purser, G., Carter, C.G., 2011. The effects of changing feeding frequency simultaneously with seawater transfer in Atlantic salmon Salmo salar L. smolt. AQUACULT INT, 1-12.

Forsberg, O. I. 1994. Modelling oxygen consumption rates of post-smolt Atlantic salmon in commercial-scale, land based farms. Aquaculture International : 180-196

Forsberg, O. I. 1995a. Empirical investigations on growth of post-smolt Atlantic salmon (Salmo salar L.) in land based farms. Evidence of a photoperiodic influence. Aquaculture 133: 235-248

Forsberg, O. I. 1995b. Oxygen consumption of post-smolt Atlantic salmon during crowding and handling stress. Aquaculture International 3: 55-59

Freedom Food Ltd, 2007. RSPCA welfare standards for farmed Atlantic salmon, july 2007.

Fry, F.E.J. 1947. Effects of the environment on animal activity. University of Toronto Studies, Biological Series No. 55. Publications of the Ontario Fisheries Research Laboratory No. 68.

FSBI, 2002. Fish Welfare (Briefing Paper 2). Fisheries Society of the British Isles. Granta Information Systems: Cambridge, UK.

Galhardo L, Oliveira RF. 2009. Psychological stress and welfare in fish. Annu Rev Biomed Sci 11:1-20.

Formatert: Engelsk (Storbritannia)

Gjedrem, T., 1993. Miljø for oppdrettsfisk. Fiskeoppdrett-Vekstnæring for distriktsNorge. Gjedrem, T., (Ed). Landbruksforlaget AS, Otta, Norway

Gjerde, B., Pante, M. J., Baeverfjord, G. 2005. Genetic variation for a vertebral deformity in Atlantic salmon (Salmo salar). Aquaculture 244: 77-87

Goede, R.W., Barton, B.A., 1990. Organismic indices and an autopsy-based assessment as indicators of health and condition of fish. Am. Fish. Soc. Symp. 8, 93-108.

Goncalves, J., Carraca, S., Damasceno-Oliveira, A., Fernandez-Duran, B., Diaz, J., Wilson, J. and Coimbra, J. 2006. Effect of Reduction in Water Salinity on Osmoregulation and Survival of Large Atlantic Salmon Held at High Water Temperature. North American Journal of Aquaculture 68: 324-329

Grini, A., Hansen, T., Berg, A., Wargelius, A., Fjelldal, P.G., 2011. The effect of water temperature on vertebral deformities and vaccine-induced abdominal lesions in Atlantic salmon, *Salmo salar* L. J. Fish Dis. Accepted.

Grimnes, A., Jakobsen, P.J. 1996. The physiological effects of salmon lice infection on post-smolt of Atlantic salmon. Journal of fish biology 48: 1179-1194

Formatert: Engelsk (Storbritannia)

Grøttum, J. A., Sigholt, T. 1998. A model for oxygen consumption of Atlantic salmon (Salmo salar) based on measurements of individual fish in a tunnel respirometer. Aquaculture Engineering : 241-251

Guerrero-Tortolero, D.A., Bromage, N., 2008. Growth and maturation of Atlantic salmon (Salmo salar) populations with different grilse proportions under natural photoperiod and superimposed nighttime light, Aquaculture 285, 63-66

Hamre, K., Christiansen, R., Waagbø, R., Maage, A., Torstensen, B. E., Lygren, B., Lie, Ø., Wathne, E., Albrektsen, S., 2004. Antioxidant vitamins, minerals and lipid levels in diets for Atlantic salmon (Salmo salar, L.): effects on growth performance and fillet quality. Aquaculture Nutrition 10: 113-123

Handeland, S. O., Berge, Å., Björnsson, B. Th., Lie, Ø., Stefansson, S. O., 2000. Seawater adaptation by out-of-season Atlantic salmon (Salmo salar L.) smolts at different temperatures. Aquaculture 181: 377-396

Handeland, S. O., Imsland, A. K., Stefansson, S. O. 2008. The effect of temperature and fish size on growth, feed intake, food conversion efficiency and stomach evacuation rate of Atlantic salmon post-smolts. Aquaculture 283: 36-42

Hansen, T., Stefanssin, S., Taranger, G. L., 1992. Growth and sexual maturation in atlantic salmon, Salmon salar L., reared in sea cages at two different light regimes. Aquaculture Research 23, 275-280

Hansen, H.P., 1999. Determination of oxygen. In: Methods of Seawater Analysis. Grasshoff, K., Kremling, K., Ehrhardt, M. (Eds.). Wiley-VCH, Weinheim, Germany, pp 75-90.

Hansen, T., Fjelldal, P. G., Yurtseva, A., Berg, A., 2010. A possible relation between growth and number of deformed vertebrae in Atlantic salmon (*Salmo salar* L.). Journal of Applied Ichthyology 26: 355-359

Helfman, G. S., Colette, B. B., Douglas, E. F., 1997. Oxygen, Metabolism and Energetics. In: The Diversity of Fishes. Blackwell Science, Massachusetts, USA, pp. 51-68

Herbinger, C. M., Friars, G. W. 1991. Correlation between condition factor and total lipid content in Atlantic salmon, Salmo salar L., parr. Aquaculture Research 4: 527-529

Hevrøy, E. M., Boxaspen, K., Oppedal, F., Taranger, G. L., Holm, J. C. 2003. The effect of artificial light treatment and depth on the infestation of the sea louse Lepeophtheirus salmonis on Atlantic salmon (Salmo salar L.) culture. Aquaculture 220: 1-14

Holm, M., Holst, J. C., Hansen, L. P., 2000. Spatial and temporal distribution of post-smolts of Atlantic salmon (*Salmo salar* L.) in the Norwegian Sea and adjacent areas. ICES Journal of Marine Science 57: 955-964.

Holst, J.C., Jakobsen, P., Nilsen, F., Holm, M., Asplin, L., Aure, J. 2003. Mortality of Seaward-Migrating Post-Smolts of Atlantic Salmon Due to Salmon Lice Infection in Norwegian Salmon Stocks. In: Salmon at the Edge. Mills, D. (Ed.). Blackwell Science Ltd, pp. 136-137

Huntingford, F.A., Adams, C., Braithwaite, V.A., Kadri, S., Pottinger, T.G.,, Sandøe, P., Turnbull, J.F., 2006. Current issues in fish welfare. Journal of Fish Biology 68(2): 332-372.

Huntingford, F. A. and Kadri, S., 2008. Welfare and Fish, in Fish Welfare (ed E. J. Branson), Blackwell Publishing Ltd, Oxford, UK.

Formatert: Engelsk (Storbritannia)

Formatert: Engelsk (Storbritannia)

Huse, I., Holm, J.C., 1993. Vertical distribution of Atlantic salmon (Salmo salar) as a function of illumination. J. Fish Biol. 43, 147-156.

Håstein, T., Scarfe, A.D. and Lund, V.L., 2005. Science based assessment of welfare: aquatic animals. Revue scientifique et technique (International Office of Epizootics) 24, 529–547.

Iversen, M., Finstad, B. & Nilssen, K.J. 1998 Recovery from loading and transport stress in Atlantic salmon (Salmo salar L.) smolts. Aquaculture, 168, 387–394

Iversen, M., Finstad, B., McKinley, R.S., Eliassen, R.A., Carlsen, K.T., Evjen, T. 2005. Stress responses in Atlantic salmon (Salmo salar L.) smolts during commercial well boat transports, and effects on survival after transfer to sea. Aquaculture : 373-382

Javaid, M.Y., and Anderson, J.M. 1967a. Thermal acclimation and temperature selection in Atlantic salmon, Salmo salar, and rainbow trout, Salmo gairdneri. J. Fish. Res. Board Can. 24: 1507–1513.

Jensen, P., Toates, F.M., 1993. Who needs 'behavioural needs'? Motivational aspects of the needs of animals. Applied Animal Behaviour Science 37, 161-181.

Jobling, M., Reinsnes, T.-G., 1986. Physiological and social constraints on growth of Arctic charr, Salvelinius alpines L.: an investigation of factors leading to stundting. Journal of Fish Biology 28: 379-384.

Johansson, D., Ruohonen, K., Kiessling, A., Oppedal, F., Stiansen, J.E., Kelly, M., Juell, J.-E. 2006. Effect of environmental factors on swimming depth preferences of Atlantic salmon (Salmo salar L.) and temporal and spatial variations in oxygen levels in sea cages at a fjord site. Aquaculture 254: 594-605

Johansson, D., Juell, J.-E., Oppedal, F., Stiansen, J.E., Ruohonen, K. 2007. The influence of the pycnocline and cage resistance on current flow, oxygen flux and swimming behaviour of Atlantic salmon (Salmo salar L.) in production cages. Aquaculture 265: 271-287

Johansson, D., Ruohonen, K., Juell, J.-E., Oppedal, F. 2009. Swimming depth and thermal history of individual Atlantic salmon (Salmo salar L.) in production cages under different ambient temperature conditions. Aquaculture 290: 296-303

Jonsson, N., Jonsson, B., Hansen, L. P. 1997. Changes in proximate composition and estimates of energetic costs during upstream migration and spawning in Atlantic salmon Salmo salar. Journal of Animal Ecology : 425-436

Juell, J. E. (1995). The behaviour of Atlantic salmon in relation to efficient cage-rearing. Reviews in Fish Biology and Fisheries 5, 320–335.

Juell, J.-E., Bjordal, Å., Fernö, A., Huse, I., 1994. Effect of feeding intensity on food intake and growth of Atlantic salmon, Salmo salar L., in sea cages. Aquaculture and Fisheries Management 25, 453-464.

Juell, J.-E., Oppedal, F., Boxaspen, K., Taranger, G.L., 2003. Submerged light increases swimming depth and reduces fish density of Atlantic salmon Salmo salar L. In production cages. Aquaculture Research 34, 469-477

Juell, J-E., Fosseidengen, J. E. 2004. Use of artificial light to control swimming depth and fish density of Atlantic salmon (Salmo salar) in production cages. Aquaculture 233: 269-282

Juell, J.-E., Fosseidengen, J. E. Vågseth, T., Kristiansen, T. 2008. Wealth report. Effects of environmental variation and crowding and sorting events on swimming and feeding behaviour of caged Atlantic Salmon. European commision :

Formatert: Engelsk (Storbritannia)

Formatert: Engelsk (Storbritannia)

Formatert: Engelsk (Storbritannia)

Jørgensen, E.H., Jobling, M., 1992. Feeding behaviour and effect of feeding regime on growth of Atlantic salmon, *Salmo salar*. Aquaculture 101, 135-146.

Jørgensen. E.H., Jobling, M., 1994. Feeding and growth of exercised and unexercised juvenile Atlantic salmon in freshwater, and performance after transfer to seawater. Aquacult. Int. 2, 154-164.

Kadri, S., Metcalfe, N.B., Huntingford, F. A., Thorpe, J.E., 1991. Daily feeding rhythms in Atlantic salmon in sea cages. Aquaculture 92, 219-224.

Kent M.L., Poppe T.T., Infectious diseases of cold-water fish in marine and brackish water. In: Lim L.H.S. (ed). Diseases and Disorders of Finfish in Cage Culture. CABI Publishing , Oxford, UK. pp 61-105.

Korsøen, Ø.J., Dempster, T., Fjelldal, P.G., Oppedal, F., Kristiansen, T.S., 2009. Long-term culture of Atlantic salmon (Salmo salar L.) in submerged cages during winter affects behaviour, growth and condition. Aquaculture 296, 373-381

Korte et al., 2007 S.M. Korte, B. Olivier and J.M. Koolhaas, A new animal welfare concept based on allostasis, Physiology and Behaviour 92 (2007), pp. 422–428.

Kråkenes, R.,Hansen, T., Stefansson, S. O. Taranger, G. L., 1991. Continuous light increases growth rate of Atlantic salmon (Salmo salar L.) postsmolts in sea cages . Aquaculture 95: 281-287

Latremouille, D.N., 2003. Fin erosion in aquaculture and natural environments. Rev. Fish. Sci. 11, 315-335.

Leclercq, E., Migaud, H., Taylor, J. F., Hunter, D. 2010. The use of continuous light to suppress pre-harvest sexual maturation in sea-reared Atlantic salmon (Salmo salar L.) can be reduced to a 4-month window. Aquaculture Research : 709-714

Leclercq, E., Taylor, J.F., Sprague, M., Migaud, H., 2011. The potential of alternative lighting-systems to suppress pre-harvest sexual maturation of 1+ Atlantic salmon(Salmo salar) post-smolts reared in commercial sea-cages. Aquaculture Engineering 44, 35-47

Leung K. Y., Stevenson R.M.W. 1988. Characteristics and distribution of extracellular proteases from Aeromonas hydrophila. J Gen Microbiol 134:151-160. DOI: 10.1099/00221287-134-1-151.

Lijalad, M., Powell, M.D., 2009. Effects of lower jaw deformity on swimming performance and recovery from exhaustive exercise in triploid and diploid Atlantic salmon Salmo salar L. Aquaculture 290, 145-154

Lorenzen, E. 1999. Infeksjoner med Flavobacterium og Flexibacter. In: Poppe, T. (Ed) Fiskehelse og sykdommer, Universitetsforlaget.

MacIntyre, C.M., Ellis, T., North, B.P., Turnbull, J.F. 2008. The Influences of Water Quality on the Welfare of Farmed Rainbow Trout: a review. Fish welfare, Branson, E.J.(ed) : 150-184.

Makino K, Onuma TA, Kitahashi T, Ando H, Ban M, Urano A. (2007). Expression of hormone genes and osmoregulation in homing chum salmon: A mini review. General and Comparative Endocrinology 152: 304-309.

McKenzie, D.J., Higgs, D.A., Dosanjh, B.S., Deacon, G., Randall, D.J. 1998. Dietary fatty acid composition influences swimming performance in Atlantic salmon (*Salmo salar*) in seawater. Fish Physiology and Biochemistry : 111-122

Formatert: Engelsk (Storbritannia)

Formatert: Engelsk (Storbritannia)

McCormick, S.D., Shrimpton, J.M., Carey, J.B., O'Dea, M.F., Sloan, K.E., Moriyama, S., Björnsson, B.T., 1998. Repeated acute stress reduces growth rate of Atlantic salmon parr and alters plasma levels of growth hormone, insulin-like growth factor I and cortisol. Aquaculture 168: 221-235

Migaud, H., Cowan, M., Taylor, J., Ferguson, H.W., 2007. The effect of spectral composition and light intensity on melatonin, stress and retinal damage in post-smolt Atlantic salmon, Salmo salar. Aquaculture 270, 390–404.

Mørkøre, T., Rørvik, K.-A., 2001. Seasonal variations in growth, feed utilisation and product quality of farmed Atlantic salmon (Salmo salar) transferred to seawater as 0+ smolts or 1+ smolts. Aquaculture 199: 145-157.

Nash, R.D.M., Valencia, A.H., Geffen, A.J., 2006. The Origin of Fulton's Condition Factor-Setting the Record Straight. Fisheries 31, 236-238.

Nilsen A, Bjøru B, Vigen J, Oppedal F, Høy E. Evaluering av metoder for badebehandling mot lakselus i stormerd. Veterinærinstituttets rapportserie 17-2010. Oslo, Norway: Veterinærinstituttet; 2010.

Noga, E.J., 2000. Skin ulcers in fish: Pfiesteria and other etiologies. Toxicologic pathology, 807-823.

Nolan, D.T., Reilly, P., Bonga, S.E.W 1999. Infection with low numbers of the sea louse, Lepeophtheirus salmonis, induces stress-related effects in post-smolt Atlantic salmon (Salmo salar) . Canadian Journal of Fisheries and Aquatic Sciences 56: 947-959.

Nordgarden, U., Oppedal, F., Taranger, G.L., Hemre, G.-I., Hansen, T., 2003. Seasonally changing metabolism in Atlantic salmon (Salmo salar L.) I – Growth and feed conversion ratio

North, B.P., Ellis, T., Bron, J., Knowles, T.G., Turnbull, J.F., 2008. 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, pp. 243-270.

O'Flynn, F. M., McGeachy, S.A., Friars, G. W., Benfey, T. J., Bailey, J. K., 1997. Comparison of cultured triploid and diploid Atlantic salmon (*Salmo salar* L.). ICES Journal of Marine Science 54: 1160-1165

Oppedal, F., Taranger, G. L., Juell, J.-E., Fosseidengen, J. E., Hansen, T. 1997. Light intensity affects growth and sexual maturation of Atlantic salmon (Salrno salar) postsmolts in sea cages. Aquat. Living Resour. 10: 351-357

Oppedal, F., Taranger, G.L., Juell, J.E., Hansen, T., 1999. Growth, osmoregulation and sexual maturation of underyearling Atlantic salmon smolt Salmo salar L. exposed to different intensities of continuous light in sea cages. AQUAC RES 30, 491-499.

Oppedal, F., Juell, J-E., Taranger, G. L., Hansen, T. 2001. Artificial light and season affects vertical distribution and swimming behaviour of post-smolt Atlantic salmon in sea cages. Jounal of Fish Biology 58: 1570-1584

Oppedal, F., Taranger, G.L., Hansen, T., 2003. Growth performance and sexual maturation in diploid and triploid Atlantic salmon (Salmo salar L.) in seawater tanks exposed to continuous light or simulated natural photoperiod. Aquaculture 215, 145-162

Oppedal, F., Berg, A., Olsen, R.E., Taranger, G.L., Hansen, T., 2006. Photoperiod in seawater influence seasonal growth and chemical composition in autumn sea-transferred Atlantic salmon (Salmo salar L.) given two vaccines, Aquaculture 254, 396–410.

Formatert: Engelsk (Storbritannia)

Formatert: Engelsk (Storbritannia)

Formatert: Engelsk (Storbritannia)

Oppedal, Juell, J.E., Johansson, D. 2007. Thermo- and photoregulatory behaviour of caged Atlantic salmon: Implication for photoperiod management and fish welfare. Aquaculture 265: 70-81

Oppedal, F., Dempster, T., Stien, L. H. 2011a. Environmental drivers of Atlantic salmon behaviour in sea-cages: A review. Aquaculture 311, 1-18

Oppedal. F., Vågset, T., Dempster, T., Juell, J-E., Johansson, D., 2011b. Fluctating sea-cage environments modify the effects of stocking densities on production and welfare parameters of Atlantic salmon (Salmo salar L.). Aquaqulture 315, 361-368.

Osland, H., Sandvik, J.I., Holm, J., Heuch, P.-A., Bakke, S., 2001. Studie av lakseluspåslag og tilvekst hos Atlantisk laks (Salmo salar) i nedsenkede merder. HSF-report, R-NR 4/01. 22 pp. (In Norwegian).

Ostland, V.E., Byrne, P.J., Hoover, G., Ferguson, H.W., 2000. Necrotic myositis of rainbow trout, Oncorhynchus mykiss (Walbaum): proteolytic characteristics of a crude extracellular preparation from Flavobacterium psychrophilum. J. Fish Dis. 23, 329-336.

Panksepp, 2005 J. Panksepp, Affective consciousness: core emotional feelings in animals and humans, Cognition and Consciousness vol. 14 (2005), pp. 30–80.

Pelis, R.M., McCormick, S.D., 2003. Fin development in stream- and hatchery-reared Atlantic salmon. Aquaculture 220, 525-536.

Persson, P., Sundell, K., Björnsson, B. Th., Lundqvist, H., 1998. Calcium metabolism and osmoregulation during sexual maturation of river running Atlantic salmon. Journal of Fish Biology 52: 334–349.

Peterson, R.H., Harmon, P.R., 2005. Changes in condition factor and gonadosomatic index in maturing and non-maturing Atlantic salmon (Salmo salar L.) in Bay of Fundy sea cages, and the effectiveness of photoperiod manipulation in reducing early maturation. Aquaculture Research 36, 882-889

Plantalech Manel-La, N., Thorstad, E.B., Davidsen, J.G., Økland, F., Sivertsgård, R., McKinley, R.S., Finstad, B. 2009. Vertical movements of Atlantic salmon post-smolts relative to measures of salinity and water temperature during the first phase of the marine migration. Fisheries Management and Ecology 16: 147-154

Pickering, A.D., 1993. Growth and stress in fish production, Aquaculture 111, 51-63

Pike, A. W., Wadsworth, S.L. 1999. Sealice on Salmonids: Their Biology and Control. Advances in Parasitology 44: 233-337

Porter, M. J.R., Duncan, N. J., Mitchell, D., Bromagea, N. R. 1999. The use of cage lighting to reduce plasma melatonin in Atlantic salmon (*Salmo salar*) and its effects on the inhibition of grilsing. Aquaculture 176: 237-244

Priede, M., 2002. Biology of salmon. In: Handbook of Salmon Farming. Stead M., Lindsay, L. (Eds.). Praxis Publishing Ltd, Chichester, UK., pp. 1-35.

Rikardsen, A. H., Haugland, M., Bjørn, P.A., Finstad, B., Knudsen, R., Dempson, J.B., Holst, J.C., Hvidsten, N.A., Holm, M., 2004. Geographic differences in early marine feeding of Atlantic salmon post-smolts in Norwegian fjords. Journal Fish Biology 64: 1–25.

Rodger H.D. & McArdle J.F. (1996) An outbreak of amoebic gill disease in Ireland. Veterinary Record 139, 348–349.

Ross, N.W., Firth, K.J., Aniping, W., Burka, J. F., Johnson, S. C. 2000. Changes in hydrolytic enzyme activities of naïve Atlantic salmon Salmo salar skin mucus due to infection with

Formatert: Engelsk (Storbritannia)

Formatert: Engelsk (Storbritannia)

Formatert: Engelsk (Storbritannia)

the salmon louse Lepeophtheirus salmonis and cortisol implantation. Diseases of aquatic organisms 41: 43-51

Rosseland 2002. Vannkvalitetens betydning for fiskehelsen. In: Fiskehelse og fiskesykdommer, Poppe T. (Ed) : 240-251

Rosten, T., Åtland, Å., Kristensen, T., Rosseland, B. O., Braathen, B., 2004. Vannkvalitet og dyrevelferd. Mattilsynet, Rapport 09.08.2004.

Rørå, A. M. B., Kvåle, A., Mørkøre, T., Rørvik, K.-A., Steien, S. H., Thomassem, M.S., 1998. Process yield, colour and sensory quality of smoked Atlantic salmon (Salmo salar) in relation to raw material characteristics. Food Research International 31: 601-609.

Saunders, R. L., Henderson, E.B., Glebe, B. D., 1982. Precocious sexual maturation and smoltification in male Atlantic salmon (*Salmo salar*). Aquaculture 28: 211-229

Schreck, C.B., Olla, B.L., Davis, M.W. 1997. Behavior responses to stress. In: Iwama, G.K., Pickering, A.D., Sumpter, J.P., Schreck, C.B. (Eds.), Fish Stress and Health in Aquaculture. Soc. Exp. Biol. : 145-170

Shimmura, T., Bracke, M.B.M, De Mol, R.M., Hirahara, S., Uetake, K., Tanaka, T., 2011. Overall welfare assessment of laying hens: Comparing science based, environment based and animal based assessments. Animal Science Journal 82, 150-160.

Sigholt, T., Finstad, B. 1990. Effect of low temperature on seawater tolerance in Atlantic Salmon (*Salmo salar*) Smolts.Aquaculture 84: 167-172.

Sinnot, R., 2002. Fish farming and the feed companies. In: Handbook of Salmon Farming. Stead, S.M., Laird, L. (Eds), Praxis Publishing Ltd, Chichester, UK, pp. 105-186.

Skuladottir, G.V., Schioth, H.B., Gudmundsdottir, E., Richards, B., Gardarsson, F. and Jonsson, L., 1990. Fatty-acid composition of muscle, heart and liver lipids in Atlantic salmon, Salmo salar, at extremely low environmental-temperature. Aquaculture 85, pp. 71–80

Skugor, S., Glover, K. A., Nilsen, F., Krasnow, A., 2008. Local and systemic gene expression responses of Atlantic salmon (*Salmo salar* L.) to infection with the salmon louse (*Lepeophtheirus salmonis*). BMC Genomics 2008, 9:498,

Smith, I. P., Metcalfe, N. B., Huntingford, F. A. & Kadri, S. (1993). Daily and seasonal patterns in the feeding behaviour of Atlantic salmon (*Salmo salar* L.) in a sea cage. Aquaculture 117, 165–178.

Sneddon, L.U., 2003. The evidence for pain in fish: the use of morphine as an analgesic. Applied Animal Behaviour Science 83: 153-162

Skugor, S. Glover, K.A., Nilsen, F., Krasnow, A. 2008. Local and systemic gene expression responses of Atlantic salmon (Salmo salar L.) to infection with the salmon louse (Lepeophteirus salmonis).. BMC Genomics 9, 1-18

Soares, S., Green, D.M., Turnbull, J.F., Crumlish, M., Murray, A.G. 2011. A baseline method for benchmarking mortality losses in Atlantic salmon (*Salmo salar*) production. Aquaculture 314: 7-12

Stead, S.M., Laird, L., 2002. Handbook of salmon farming, Springer, London, 30-34.

Stefansson, SO, Björnsson, BTh, Ebbesson, LO, & McCormick, SD 2008. Smoltification. In: Finn, R.N., Kapoor, B.G. (Eds.), Fish Larval Fysiol. 639-681

Steinhausen et al., 2008 M.F. Steinhausen, E. Sandblom, E.J. Eliason, C. Verhille and A.P. Farrell, The effect of acute temperature increases on the cardiorespiratory performance of

Formatert: Engelsk (Storbritannia)

Formatert: Engelsk (Storbritannia)

resting and swimming sockeye salmon (Oncorhynchus nerka), J. Exp. Biol. 211 (2008), pp. 3915–3926.

St-Hilaire, S., Ribble, C., Whitaker, D.J., Kent, M., 1998. Prevalence of Kudoa thyrsites in sexually mature and immature pen-reared Atlantic Salmon (*Salmo salar*) in British Columbia, Canada. Aquaculture 162: 1–2.

Stephen, C., Ribble, S. 1995. An evaluation of surface moribund salmon as indicators of seapen disease status . Aquaculture 133: 1-8

Stevens, E. D., Sutterlin, A., Cook, T. 1998. Respiratory metabolism and swimming performance in growth hormone transgenic Atlantic salmon. Can. J. Fish. Aquat. Sci. 55: 2028-2035

Stien, L. H., Kristiansen, T., Danielsen, T. L., Torgersen, T., Oppedal, F., Fosseidengen, J.E., 2009. Fra utsett til slakt (In Norwegian). In Kyst og Havbruk 2009, pp. 160–163. Ed. By A. L. Agnalt, I. Bakketeig, T. Haug, J. A. Knutsen, and I. Opstad. Institute of Marine Research, Bergen. 197 pp.

Sundh, H., Kvamme, B.O., Fridell, F., Olsen, R.E., Ellis, T., Taranger, G.L., Sundell, K., 2010. Intestinal barrier function of Atlantic salmon (*Salmo salar* L.) post smolts is reduced by common sea cage environments and suggested as a possible physiological welfare indicator. BMC Physiology 10:22.

Sveier, H., Lied, E., 1998. The effect of feeding regime on growth, feed utilisation and weight dispersion in large Atlantic salmon (*Salmo salar*) reared in seawater. Aquaculture 165, 333-345.

Takle, H., Castro, V., Grisdale-Helland, B., Helland, S., Tørud, B., Kristensen, T., 2010. Aerob utholdenhetstrening for bedret hjertefunksjon og helse hos oppdrettslaks: oppfølging og videreutvikling av konseptet trening av fisk. Final project report for FHF, Norway. ISBN: 978-82-7251-738-9. 46 pp.

Taranger, G.L., Daae, H., Jørgensen, K.O., Hansen, T., 1995. Effects of continuous light on growth and sexual maturation in seawater reared Atlantic salmon. In: Goetz, F., Thomas, P. (Eds.), Proc. 5th Int. Symp. Reproductive Physiology in Fish. University of Texas, Austin, Texas, 2–8 July, 1995, p. 200.

Taranger, G.L., Haux, C., Stefansson, S.O., Björnsson, B.T., Walther, B.T.,Hansen, T., 1998. Abrupt changes in photoperiod affect age at maturity, timing of ovulation and plasma testosterone and oestradiol-17β profiles in Atlantic salmon, Salmo salar. Aquaculture 162, 85-98

Taranger, G.L., Haux, C, Hansen, T., Stefansson, S.O., Björnsson, B.T., Walther, B.T., Kryvi, H., 1999. Mechanisms underlying photoperiodic effects on age at sexual maturity in atlantic salmon, *Salmo salar*. Aquaculture 177, 47-60

Thorstad, E. B., Whoriskey, F., Rikardsen, A. h., Aarestrup. K. 2011. Aquatic Nomads: the Life and Migrations of the Atlantic Salmon. In: Atlantic Salmon Ecology, Aas, Ø, Einum, S., Klemetsen, A., Skurdal, J. (eds). Blackwell Publishing Ltd, Oxford, UK, pp.1-32

Torgersen, T., Bracke, B. M., Kristiansen, T. S., 2011. Reply to Diggles et al. -Ecology and welfare of aquatic animals in wild capture fisheries. Reviews in Fish Biology and Fisheries, Accepted manuscript.

Formatert: Engelsk (Storbritannia)

Totland, G. K., Kryvi, H., Jødestøl, K. A., Christiansen, E. N., Tangerås, A., Slinde, E. 1987. Growth and composition of the swimming muscle of adult Atlantic salmon (Salmo salar L.) during long-term sustained swimming . Aquaculture 66: 299-313

Tunsjo, H.S., 2009. Moritella viscosa, the aetiological agent of winter ulcer: Interactions with hosts and environement. PhD thesis, Norwegian School of Veterinary Science

Turnbull, J., Bell, A., Adams, C., Bron, J., Huntingford, F. 2005. Stocking density and welfare of cage farmed Atlantic salmon: application of multivariate analysis. Aquaculture 243: 121-132

Tvenning, H. 1990. Sammenhengen mellom lengde og vekt. In: Fiskeoppdrett, Ascehoug, Oslo, Norway: 25

Ursinus, WW, F Schepers, RM de Mol, MBM Bracke, JHM Metz, PWG Groot Koerkamp, 2009. COWEL: A decision support system husbandry systems for dairy cattle on welfare. Animal Welfare, 18, 454-552

Vera, L.M., Migaud, H., 2009. Continuous high light intensity can induce retinal degeneration in Atlantic salmon, Atlantic cod and European sea bass. Aquaculture 296, 150–158.

Vigen, 2008 Vigen, J., 2008. Oxygen variation within a seacage, Master Thesis. Department of Biology. University of Bergen, Bergen, 73 pp.

Wagner, G.N, Fast, M.D,, Johnson, S.D. 2008. Physiology and immunology of Lepeophtheirus salmonis infections of salmonids. Trends in Parasitology 24: 176-183

Wallace, J.C., Kolbeinshavn, A., Aassjord, D., 1988. Observations on the effect of light intensity on the growth of Arctic charr fingerlings (Salvelinus alpinus) and salmon fry (Salmo salar). Aquaculture 72, 81–84.

WEALTH, 2008. Welfare and health in sustainable aquaculture. Report from EU project WEALTH, www.wealth.imr.no

Witten, P.E., Gil-Martens, L., Hall, B.K., Huysseune, A., Obach, A., 2005. Compressed vertebrae in Atlantic salmon (*Salmo salar*): evidence for metaplastic chondrogenesis as a skeletogenic response late in ontogeny. Diseases of Aquatic Organisms 64: 237–246.

Wolffrom, T., Lopez, M, 2004. Farmed fish and welfare, European commission, Directorate–General for fisheries, pp. 1–39

Formatert: Engelsk (Storbritannia)

Formatert: Engelsk (Storbritannia)

Side 16: [1] Slettet	Lars H. Stien	30.08.2011 16:31:00

Early draft/brainstorm DELETE:
"Disease outbreak is severe for salmon welfare in sea cages. It is outside the scope of this text to do a detailed analysis of the different diseases that may occur, but we will try to do a brief evaluation of the most common diseases in their overall impact for salmon in an infected cage in terms of mortality and intensity: severe (high mortality), intermediate (some mortality) and mild (low mortality). Outbreak of Infectious pancreatic necrosis (IPN) have various outcomes; from little to no mortality to extreme mortality (100%) (Biering 1999; Bornø 2006). Most outbreaks of ISA occur at water temperatures between 5 and 15°C, with relative low mortalities at low temperatures (<10%) and high mortality at high temperatures (100%), there has however been cases where an ISA outbreak has stopped as soon as the temperature increased above 15°C (Falk and Thorud, 1999). Pancreas disease (PD) can last for a long time and the leads emaciated fish, mortality is normally low, but can be as high (50%) if the fish are stressed (Christie 1999; Bornø 2006). Heart and skeletal muscle inflammation (HSMI) has relative low mortality (<10%) (Bornø, 2006). Cardio myopathy syndrome (CMS) is a cronic disease with low short term mortality but accumulated mortality can be high (30%). Winter ulcer normally leads to relative low mortality (0-10%) (Larsen and Pedersen, 1999). Acute furunculosis can potentially give high mortality and the fish dies within few days (Eggset and Gudmundsdottir, 1999).
BKD...
Piscirickettsiose...
Vibriose?
"

Side 16: [2] Merknad [BM6]	Bracke, Marc	27.06.2011 19:48:00

MB: 3 lines down the word copepod is used; choose which one.

Side 19: [3] Slettet	Lars H. Stien	30.08.2011 16:43:00

, however, sufficient data to justify fin erosion as a significant fish welfare indicator/issue (Ellis et al., 2008). Being an externally visible injury, fin damage represents an intuitive [BM1]and meaningful welfare indicator easily recognized by farmers and informed consumers (Ellis et al., 2008). While most studies on nociception in fish have focused on the head region or the body, Chervova (1997) demonstrated experimentally that fish fins are capable of nociception. As fin damage represents injury to live tissue capable of nociception it is most likely

Side 19: [4] Slettet	Lars H. Stien	30.08.2011 16:48:00

that fin erosion is associated with pain

Side 19: [5] Slettet	Lars H. Stien	30.08.2011 16:48:00

. The fins fulfil important functions in both locomotion and intraspecific communication in salmonids (Pelis and McCormick, 2003; Abbot and Dill, 1985) and fin erosion and thus poor fin condition may

Side 19: [7] Slettet	Lars H. Stien	30.08.2011 17:05:00

functional impairment following fin erosion has yet to be demonstrated scientifically. The breakdown of the epithelial barrier during active fin erosion may disrupt osmotic homeostasis and can thus cause severe stress to

Side 19: [8] Slettet	Lars H. Stien	30.08.2011 17:05:00

the fish (Clayton et al., 1998). Furthermore, epithelial breakdown may facilitate secondary infection by facultative bacteria, or the entry of other systemic infections (Goede and Barton, 1990; Ellis et al., 2008). The condition of the fins may thus affect the survival, health and welfare of farmed salmonids strongly. [MB: This kind of summary statement at the end of each para expressing how the WI related to WCat may strengthen the paper; I was asked the reviewers/editor of the wallowing paper (in Anim Welf) to do just that. But, from reading further down, it’s ok the way it is now.]

Side 20: [9] Slettet	Lars H. Stien	30.08.2011 17:03:00

The integrity of the skin-scale complex is critical to the survival, health and welfare of salmonids in sea water. The scales and skin

Side 20: [10] Slettet	Lars H. Stien	30.08.2011 17:03:00

a relatively impermeable barrier to water and electrolytes, and protection against physical trauma. Epidermal damage such as scale loss, wounds and ulcers can result in loss of body water and changed ion balance, and produce

Side 20: [11] Slettet	Lars H. Stien	30.08.2011 17:03:00

can be life threatening (Bouck and Smith, 1979).

Side 20: [12] Slettet	Lars H. Stien	30.08.2011 17:03:00

lceration of as little as 10% of the body surface area can result in high acute mortality and

Side 20: [13] Slettet	Lars H. Stien	30.08.2011 17:03:00

the degree of mortality seems to be

Side 20: [14] Slettet	Lars H. Stien	30.08.2011 17:03:00

directly related to the amount of skin damage (Bouck and Smith, 1979). Sub

Side 20: [15] Slettet	Lars H. Stien	30.08.2011 17:03:00

lethal skin damage, even skin lesions that are not grossly visible, might affect the fish

Side 20: [16] Slettet	Lars H. Stien	30.08.2011 17:03:00

due to increased metabolic cost involved in wound repair and osmoregulatory perturbations. Such chronic effects can affect growth rates and fecundity negatively, and

Side 20: [17] Slettet	Lars H. Stien	30.08.2011 17:03:00

lead to an increased disease susceptibility

Side 20: [18] Slettet	Lars H. Stien	30.08.2011 17:03:00

(Noga, 2000). Furthermore, epidermal damage

Side 20: [19] Slettet	Lars H. Stien	30.08.2011 17:03:00

in itself provides access for infectious agents as wounds and non-intact mucus layers represent invasion routes for bacteria (Svendsen and Bøgwald, 1997). It is also worth noting that virus- or bacterial infections can

Side 20: [20] Slettet	Lars H. Stien	30.08.2011 17:03:00

skin damages in fish. Several bacteria in the class Flexibacteriae have been associated with

Side 20: [21] Slettet	Lars H. Stien	30.08.2011 17:03:00

skin lesions and fin erosion in fish (Bernardet, 1998; Lorenzen, 1999). Furthermore,

Side 20: [22] Slettet	Lars H. Stien	30.08.2011 17:03:00

many pathogenic fish bacteria secrete proteolytic enzymes that may

Side 20: [23] Slettet	Lars H. Stien	30.08.2011 17:03:00

massive tissue damage and consequently contribute to the invasion of

Side 20: [24] Slettet	Lars H. Stien	30.08.2011 17:03:00

pathogens (Leung & Stevenson 1988; Ostland et al., 2000). Many situations or management procedures in salmon aquaculture are associated with a high risk for mechanical damage to the skin. Examples include

Side 20: [25] Slettet	Lars H. Stien	30.08.2011 17:03:00

transport, sorting, vaccination, pumping, strong currents and high densities of fish, jelly fish burns, and viral- and parasitic infections (Tunsjø, 2009). Dramatic and adverse epidermal responses in fish can also result from

Side 20: [26] Slettet	Lars H. Stien	30.08.2011 17:03:00

non-mechanical measures i.e. various stressors such as hypo- and hyperthermia, confinement, acidity, hypoxia, drugs and chemicals (Bouck and Smith, 1979). Epidermal damage found on fish in nature is considered to be one of the best biomarkers of polluted and otherwise stressful environments (Bouck and Smith, 1979).

Linking of welfare indicators to needs

Side 20: [27] Merknad [BM10]	Bracke, Marc	27.06.2011 19:48:00

MB: Is rather weak; This should logically follow from sci evidence; -> we derived 4 levels

Side 20: [28] Formatert	Lars H. Stien	26.08.2011 11:06:00

Engelsk (Storbritannia)

Side 20: [29] Merknad [BM11]	Bracke, Marc	27.06.2011 19:48:00

MB: Delete? (& explain a bit in text how?]

Side 20: [30] Formatert	Lars H. Stien	26.08.2011 11:06:00

Engelsk (Storbritannia)

Side 20: [31] Merknad [t12]	thomast	27.06.2011 19:48:00

TT: Unfortunately, we lack good data on the interaction between low temperature and low salinity, which may be very problematic. In a review that means that it is difficult to say too much about it.

Side 20: [32] Formatert	Lars H. Stien	26.08.2011 11:06:00

Engelsk (Storbritannia)

Side 20: [33] Slettet	Bracke, Marc	27.06.2011 17:22:00

for

Side 20: [33] Slettet	Bracke, Marc	27.06.2011 17:22:00

for

Side 20: [33] Slettet	Bracke, Marc	27.06.2011 17:22:00

for

Side 20: [33] Slettet	Bracke, Marc	27.06.2011 17:22:00

for

Side 20: [33] Slettet	Bracke, Marc	27.06.2011 17:22:00

for

Side 20: [33] Slettet	Bracke, Marc	27.06.2011 17:22:00

for

for

Side 28: [34] Slettet Bracke, Marc 27.06.2011 20:26:00

not only when new scientific information becomes available but also for

Side 28: [35] Slettet Bracke, Marc 27.06.2011 20:28:00

One of the main advantages [BM2]of semantic modelling is that

Side 28: [36] Slettet Bracke, Marc 27.06.2011 20:28:00

, using the criterion that the collected

Side 28: [37] Slettet Bracke, Marc 27.06.2011 20:28:00

animal and farm situations in question