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On-farm evaluation of the Salmon Welfare Index Model (SWIM 1.0): theoretical and practical considerations

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Abstract

*The present study investigated the operational feasibility of the recently developed Salmon Welfare Index Model (SWIM 1.0) designed for Atlantic salmon (*Salmo salar *L) in production cages. Ten salmon farms containing spring smolts were visited twice, first between May and June the first year in sea cages, and secondly 2–3 months later. On each farm the SWIM 1.0 assessments were carried out for the two cages assumed by the farmer to represent the best and worst welfare status. The applied welfare indicators (WIs) were water temperature, salinity, stocking density, lighting, disturbance, daily mortality rate, appetite, sea lice infestation ratio, condition factor, emaciation state, vertebral deformation, maturation stage, smoltification state, fin condition and skin condition. The effective time to carry out the welfare evaluation was about 1.5 h per farm. The results showed some marked differences between visits; relatively larger proportions of emaciated fish were sampled during the first compared to the second visit, and more homogeneous scores of skin and fin damage were found on the second visit. The overall welfare index scores were generally in accordance with the farmers' ranking of the 'best' and the 'worst' sea cage during the first visit. Together, the findings of this study suggest that the SWIM model may be employed for documentation of animal welfare over the salmon marine production cycle. The results call attention towards re-assessment of some of the welfare indicators, improved sampling methods, and a more user-friendly interface. All-in-all, the current SWIM model is regarded as a promising candidate tool towards welfare assessment of farmed salmon.*

Keywords: *animal welfare, aquaculture, Atlantic salmon, diagnostic, sea cage, semantic modelling*

Introduction

Norwegian and EU aquaculture laws and regulations demand that farmed fish are provided with a good standard of welfare during rearing. Food and Aquaculture authorities are therefore keen for methods that can be used to assess fish welfare. However, how to assess, or even define, fish welfare is an ongoing debate and no consensus has been reached (for reviews, see Ashley 2007; Huntingford & Kadri 2008; Segner *et al* 2012). From the aquaculture industry point of view, good fish welfare is considered to be central to the successful production of high quality end products (Read 2008), and many consumers select salmon products not only based on the price or quality, but also taking into consideration the rearing conditions and animal welfare (Olesen *et al* 2010). However, to be able to assess welfare in a way that would allow it to be compared between different salmon farms and welfare assessors, a standardised and validated method for welfare assessment is needed.

With this in mind, we recently developed the Salmon Welfare Index Model (SWIM) 1.0 and 2.0 for salmon farmers and fish health veterinarians/inspectors, respectively, as tools for formalised and standardised overall welfare assessment (OWA) of Atlantic salmon (*Salmo salar* L) in sea cages (Stien *et al* 2013; Pettersen *et al* 2014). The SWIM models are based on semantic modelling (Bracke *et al* 2002) that includes extensive literature reviews on how different welfare indicators (WIs) affect salmon welfare at both group and individual level. Welfare was defined as the quality of life as experienced by the animal itself, where the experience of welfare is seen as the animals' qualitative assessment of fulfilment of their welfare needs (eg food, oxygen, thermal regulation, safety, body integrity, etc; see Bracke *et al* 1999a,b; Stien *et al* 2013). The rationale behind the choice of WIs is that they shall cover all important welfare needs, and be (semi-) quantitative and easily measureable on-farm (Stien *et al* 2013).

The WIs in SWIM 1.0 comprise a number of sea cage, environment-based WIs as well as animal-based WIs recorded at the group or individual level. The SWIM model assigns weighted scores to each indicator so as to be able to calculate

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Table 1 Farms visited, dates and production data showing estimated numbers of fish, average fish size and daily mortality between visits.

Farm ID	Cage ID	Geographical region	Farm type	Visit number	Date of visit	Days between visits	Fish (n)	Individual weight (g)	Mortality (% per day)
M1	a	Møre og Romsdal	Commercial	1	28.06		135,871	137	
M1	a	Møre og Romsdal	Commercial	2	26.10	120	133,709	1,206	0.013
M1	b	Møre og Romsdal	Commercial	1	28.06		115,350	179	
M1	b	Møre og Romsdal	Commercial	2	26.10	120	106,122	1,081	0.067
M2	a	Møre og Romsdal	Commercial	1	26.06		104,961	226	
M2	a	Møre og Romsdal	Commercial	2	25.10	121	99,799	1,311	0.041
M2	b	Møre og Romsdal	Commercial	1	26.06		122,991	90	
M2	b	Møre og Romsdal	Commercial	2	25.10	121	121,945	827	0.007
F1	a	Finnmark	Commercial	1	06.08		290,000	136	
F1	a	Finnmark	Commercial	2	26.09	51	286,559	360	0.023
F1	b	Finnmark	Commercial	1	06.08		162,000	296	
F1	b	Finnmark	Commercial	2	26.09	51	161,428	707	0.007
F2	a	Finnmark	Commercial	1	08.08		100,541	430	
F2	a	Finnmark	Commercial	2	02.10	55	100,200	918	0.006
F2	b	Finnmark	Commercial	1	08.08		91,237	320	
F2	b	Finnmark	Commercial	2	02.10	55	91,100	712	0.003
F3	a	Finnmark	Commercial	1	07.08		135,443	561	
F3	b	Finnmark	Commercial	1	07.08		153,163	510	
H1	a	Hordaland	Commercial	1	11.07		168,206	555	
H1	a	Hordaland	Commercial	2	08.10	89	161,855	1,710	0.042
H1	b	Hordaland	Commercial	1	11.07		169,317	293	
H1	b	Hordaland	Commercial	2	08.10	89	166,626	1,193	0.018
H2	a	Hordaland	Commercial	1	09.07		101,122	460	
H2	a	Hordaland	Commercial	2	09.10	92	94,670	1,766	0.069
H2	b	Hordaland	Commercial	1	09.07		102,870	632	
H2	b	Hordaland	Commercial	2	09.10	92	100,335	2,088	0.027
H3	a	Hordaland	Commercial	1	09.07		102,937	492	
H3	a	Hordaland	Commercial	2	09.10	92	101,810	1,821	0.012
H3	b	Hordaland	Commercial	1	09.07		106,753	248	
H3	b	Hordaland	Commercial	2	09.10	92	105,787	1,206	0.010
R1	a	Hordaland	Research	1	12.07		5,990	165	
R1	a	Hordaland	Research	2	10.10	90	6,273	515	
R1	b	Hordaland	Research	1	12.07		5,990	183	
R1	b	Hordaland	Research	2	10.10	93	11,754	490	
R2	a	Hordaland	Research	1	10.07		2,963	235	
R2	a	Hordaland	Research	2	11.10	93	5,170	848	
R2	b	Hordaland	Research	1	10.07		2,960	226	
R2	b	Hordaland	Research	2	11.10	93	4,739	835	

Cage ID: a is best and b is worst sea cage as indicated by the farmer (see text for details).

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Table 2 SWIM 1.0 welfare indicators (WIs) and their levels (Stien *et al* 2013).

Welfare indicators (WI)	Levels
Cage environment specific WIs	
1. Temperature (°C)	1) 10–15, 2) 7–10, 3) 16–17, 4) 3–6, 5) ≤2, ≥18, short term, 6) ≤2, ≥18, long term
2. Salinity	1) Access to brackish water, 2) Adult fish with no access to brackish water, 3) small post-smolt, maturing or clearly impaired fish with no access to brackish water
3. Oxygen	1) > 80%, all temperatures, 2) 70–80% for warm water (≈18°C), 60–80% (≈12°C), 3) 60-70% for warm water (≈18°C), 40–60% (≈12°C), 30–50% cold water (6°C), 4) < 60% for warm water (≈18°C), < 40% (≈12°C), < 30% for cold water (6°C)
4. Water current (Body lengths^{-1})	1) < 0.9, 2) 0.9 – *Ucrit*, 3) ≥ *Ucrit* (*Ucrit* refers to critical swimming speed)
5. Stocking density (kg m^{-3})	1) < 22, 2) 22–26, 3) 26–32, 4) > 32
6. Lighting	1) Optimal, 2) Sub-optimal
7. Disturbances	1) None, 2) Light, 3) Moderate, 4) Severe
Fish group-specific WIs	
Mortality (% per day)	1) At or below 10th percentile curve, 2) Below benchmark curve, 3) At the benchmark curve, 4) Above the benchmark curve, 5) At or above the 90% percentile curve, 6) At or above the 90th percentile curve, long term
Appetite (farmers' assessment)	1) Good appetite (food demand is higher than expected), 2) As expected, 3) Poor appetite
Individual fish-specific WIs	
1. Emaciation state	1) Not emaciated, 2) Potentially emaciated, 3) Positively emaciated (generally small, very thin fish of poor health)
2. Vertebral deformity state	1) No external signs of vertebral deformity, 2) Short tail of normal weight, 3) Short tail of low weight
3. Sexual maturity stage	1) Not mature, 2) Precocious male (mature during the freshwater stage), 3) Mature male, 4) Mature female
4. Smoltification state (sea water adaption state)	1) Fully smoltified (adapted to sea water), 2) Incomplete smoltification (parr; small size and with skin finger marks), but with access to fresh/brackish surface water, 3) Incomplete smoltification, only access to sea water at 7–10°C, 4) Incomplete smoltification, 10–14°C, 5) Incomplete smoltification, < 7°C, 6) Incomplete smoltification, 14–20°C
5. Fin condition	1) Normal healthy fins, nothing to comment, 2) Scar tissue or slight necrosis, 3) Moderate current skin damage and/or necrosis including splitting and/or thickening, 4) Severe skin damage and/or necrosis with bleeding and/or inflammation and/or exposed fin rays and severe tissue loss
6. Skin condition	1) Normal healthy skin, nothing to comment, 2) Scar tissue, healed, 3) Scale loss (dislocated or missing scales), 4) Superficial wound or ulcer < 1 cm^2, 5) Superficial wound or ulcer > 1 cm^2, 6) Penetrating and/or multiple wounds or ulcers possibly infected
7. Condition factor (*K*)	1) > 1.1, 2) 0.9–1.1, 3) < 0.9

overall welfare scores for the fish in the sea cage (see Stien *et al* 2013 for details) and specifies how each WI contributes (negatively or positively) to the overall scoring and which welfare needs are compromised or fulfilled/satisfied.

The present study aimed to examine the operational feasibility of SWIM 1.0 by testing the model in the field, using two contrasting sea cages per site (cages with the worst and best welfare as perceived by the farmer). Ten marine Atlantic salmon farms across Norway were visited at two time-points, so as to include both between and within farm differences, and to also include different phases during the on-growth in sea cages. Our primary goal was to investigate if SWIM 1.0 was feasible to perform operationally in the field, eg if a farm visit could be conducted within an acceptable period of time, and if the different WIs could be assessed in a sufficiently unambiguous way.

Materials and methods

Location and design of sampling programme

The ten salmon farms were located along the Norwegian coast from the Finnmark county (three farms, labelled F) in the north to Møre and Romsdal (two farms, labelled M) in mid-Norway and Hordaland (three farms labelled H, and two research facilities, labelled R) in the south-west of Norway (Table 1). All the farms with one exception were visited twice; the first visit took place during May and June 2012, and the second 2–3 months later, September to October. All farms reared smolts that were sea water transferred between April and May 2012. On the first visit, the farmer selected what he considered to be both his 'best' and 'worst' cage, labelled, respectively, as cage 'a' and 'b' for each farm, based on an evaluation of the cage's specific performance, including

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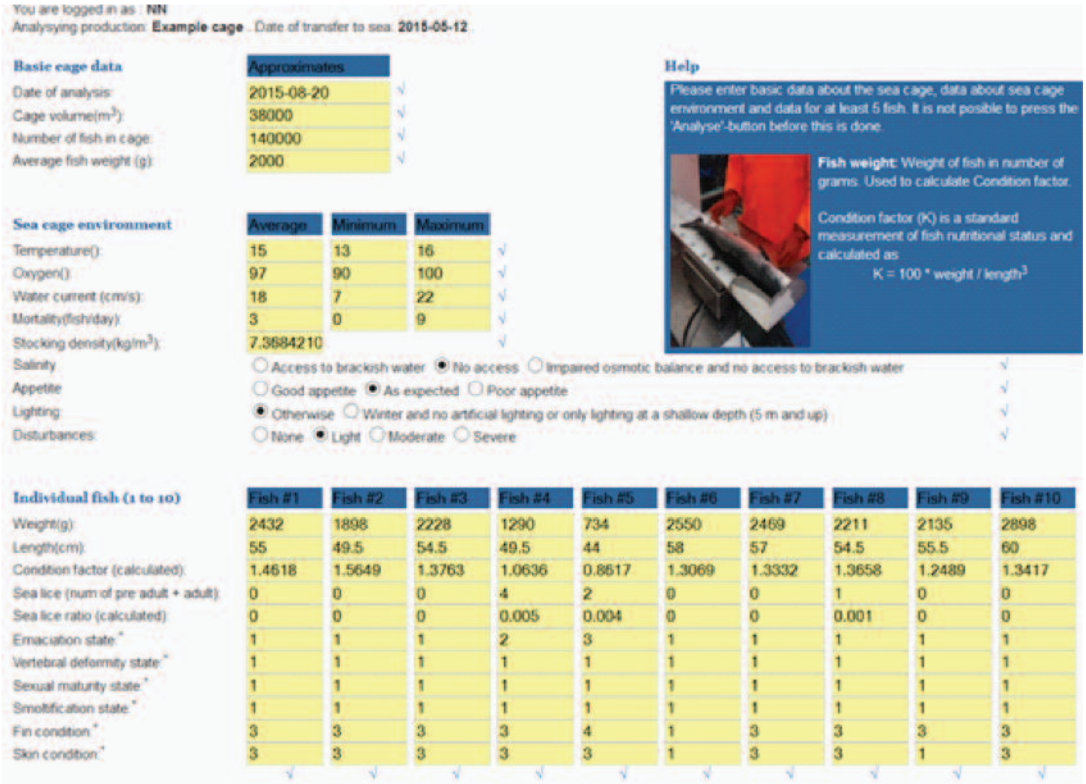
Figure 1



You are logged in as : **NN**
Analysying production: **Example cage** . Date of transfer to sea: **2015-05-12**

Basic cage data

Basic cage data	Approximates	
Date of analysis:	2015-08-20	√
Cage volume(m^3):	38000	√
Number of fish in cage:	140000	√
Average fish weight (g):	2000	√

Help

Please enter basic data about the sea cage, data about sea cage environment and data for at least 5 fish. It is not posible to press the 'Analyse'-button before this is done.

Fish weight: Weight of fish in number of grams. Used to calculate Condition factor.

Condition factor (K) is a standard measurement of fish nutritional status and calculated as

K = 100 * weight / $length^3$

Sea cage environment	Average	Minimum	Maximum	
Temperature():	15	13	16	√
Oxygen():	97	90	100	√
Water current (cm/s):	18	7	22	√
Mortality(fish/day):	3	0	9	√
Stocking density(kg/m^3):	7.3684210			√

Salinity: ○ Access to brackish water ● No access ○ Impaired osmotic balance and no access to brackish water √
Appetite: ○ Good appetite ● As expected ○ Poor appetite √
Lighting: ● Otherwise ○ Winter and no artificial lighting or only lighting at a shallow depth (5 m and up) √
Disturbances: ○ None ● Light ○ Moderate ○ Severe √

Individual fish (1 to 10)	Fish #1	Fish #2	Fish #3	Fish #4	Fish #5	Fish #6	Fish #7	Fish #8	Fish #9	Fish #10
Weight(g):	2432	1898	2228	1290	734	2550	2469	2211	2135	2898
Length(cm):	55	49.5	54.5	49.5	44	58	57	54.5	55.5	60
Condition factor (calculated):	1.4618	1.5649	1.3763	1.0636	0.8617	1.3069	1.3332	1.3658	1.2489	1.3417
Sea lice (num of pre adult + adult):	0	0	0	4	2	0	0	1	0	0
Sea lice ratio (calculated):	0	0	0	0.005	0.004	0	0	0.001	0	0
Emaciation state*:	1	1	1	2	3	1	1	1	1	1
Vertebral deformity state*:	1	1	1	1	1	1	1	1	1	1
Sexual maturity state*:	1	1	1	1	1	1	1	1	1	1
Smoltification state*:	1	1	1	1	1	1	1	1	1	1
Fin condition*:	3	3	3	3	4	1	3	3	3	3
Skin condition*:	3	3	3	3	3	1	3	3	1	3
	√	√	√	√	√	√	√	√	√	√

SWIM 1.0 recording form from the SWIM website: www.imr.no/salmowa.

estimated growth (feed conversion ratio), disease and mortality levels. The same cages were also evaluated during the second visit. In the two research facility sites, the selected pen populations were subjected to experimental treatments that were expected to negatively affect the welfare of the fish. Fish in farm R1 were subjected to starvation and transport, while fish in farm R2 were subjected to abnormally high sea lice infestation (up to 30 lice per fish) due to extended intervals between topical delousing treatments.

Recorded data

We used the mortality figures and data on cage environment derived from the farm management software to record the environmental and group-based indicators for the week preceding the farm visit. Since SWIM 1.0 is intended to be used by the farmer for evaluation of fish welfare, the data were collected based on the measurement practices and routines of each farm. In other words, methods for sampling fish and environmental parameters were not standardised between farms, and we only used equipment that was available at the farm site. The individual welfare indicator scores in SWIM 1.0 were obtained during visual evaluation of 20 fish after netting and anaesthesia. All information regarding the indicators and their scoring levels are included in the currently used SWIM 1.0 forms presented in Table 2 and Figure 1. For more details and a full explanation, see Stien *et al* (2013).

Collection of data and sampling of fish

Each farm visit consisted of an interview with the farmer to procure the information about the number and size of the fish in the cages, cage volume, and the previous week's mortalities, appetite, any treatment or handling of the fish, and the measured environmental parameters. Thereafter, the individual fish from designated cages were sampled and examined macroscopically. All farm visits were carried out by the same investigator, assisted by a second person who recorded the raw data on the forms, while the local farmer caught and released the fish back into the sea cages.

The exact manner in which individual fish were each obtained by netting from the sea cages was ultimately decided by the farmer, and depended upon farm-specific practical as well as welfare considerations. As a result, various sampling techniques were used, including luring the fish towards the surface by hand-feeding and catching them with a dip-net, using a casting net/sweep net pulled horizontally in the upper 3 m of the water column, a casting net pulled vertically from 12-m depth, and vertical winching of a big dip net (3 m in diameter) from 3-m depth. In each case, sampled fish were rapidly anaesthetised in a small tank filled with sea water in accordance with the site's common practice for sea lice counts. Within two minutes, the fish were allowed to recover from the anaesthesia in another tank before being released back into the sea cage.

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The SWIM 1.0 form

Each welfare indicator (WI) in the SWIM 1.0 form is divided into levels ranging from best to worst welfare (Table 2). The levels are mutually exclusive (ie the finding can be described by only one level) and cover the model's domain of application (ie there is always a level which describes the situation). Derived from a systematic analysis of the available literature, SWIM 1.0 attributes a weighting factor (WF) to each WI and has an ordinal indicator score (IS) for each WI level (Stien *et al* 2013). ISs are scores ranging from 0 to 1 for the worst and best levels of each WI, respectively. In addition, some WI levels are so-called knockout levels that are considered to represent a detrimental welfare status. They are given the value 0. Such scores lead, by default, to an overall welfare index (OWI) of 0 for that group or individual. If no knockout levels apply, the following three formulae are used to calculate the relative weighting factor (RWF), the indicator welfare score (IWS) and finally the OWI on a scale from worst 0 to best 1:

(1)

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

$$\mathrm{IWS}_i = \mathrm{IS}_i \cdot \mathrm{RWF}_i$$

$$\mathrm{OWI} = \sum_{i=1}^{m} \mathrm{IWS}_i$$

where m is the total number of welfare indicators in the model, WF_i and WF_j are the weighting factors of, respectively, indicator i and j. IS_i (see Table 2) is the indicator score given for WI_i. Pragmatically, the total OWI ($\mathrm{OWI}^{\mathrm{total}}$) score is based on all WIs and can be divided into three components: the welfare index $\mathrm{OWI}^{\mathrm{cage\ environment}}$ which is based on the WIs related to the sea cage environment (temperature, salinity, oxygen saturation, water current, stocking density, lighting and disturbances), the $\mathrm{OWI}^{\mathrm{fish\ group}}$ which is based on the fish-group specific WIs (daily mortality ratio and appetite), and the $\mathrm{OWI}^{\mathrm{individual\ fish}}$ which is based on the WIs related to individual fish (sea lice infestation ratio, body condition, emaciation state, vertebral deformation, maturation stage, smoltification state, fin condition and skin condition). For the $\mathrm{OWI}^{\mathrm{individual\ fish}}$ score, the average of the sampled fish is used in the calculation of the $\mathrm{OWI}^{\mathrm{total}}$ score:

(2)

$$\mathrm{OWI}^{\mathrm{total}} = \left(w_1 OWI^{\mathrm{cage\ environment}} + w_2 OWI^{\mathrm{fish\ group}} + \overline{w}_3 \overline{OWI^{\mathrm{individual\ fish}}}\right)\left(w_1 + w_2 + \overline{w}_3\right)^{-1}$$

where w_1 is the sum of the WFs included in $\mathrm{OWI}^{\mathrm{cage\ environment}}$, w_2 is the sum of the WFs included in $\mathrm{OWI}^{\mathrm{fish\ group}}$, and w_3 is the average sum of the WFs included in $\mathrm{OWI}^{\mathrm{individual\ fish}}$ calculations.

Statistical analysis

The data were analysed with the R software system Version 3.1.2 (Copyright 2014, The R Foundation for Statistical Computing, Vienna, Austria). The significance level was set at 0.05.

Results

Practical experience

The time needed to carry out SWIM 1.0 (for two sea cages) was about 1.5 h per farm when a minimum of three persons participated in the sampling and scoring of the individual fish. All farmers grasped the general idea of the model and the purpose of its use, and were motivated to participate. While all WIs specific for the fish group and for individual fish were easily attainable, some sea cage-related WIs were more difficult to obtain from farm records; no farms measured water current velocity and only two of the ten commercial farms monitored oxygen levels at the time of the farm visits. The SWIM model is flexible with regards to missing WI input, but the reduced number of environmental WIs will reduce the precision of $\mathrm{OWI}^{\mathrm{cage\ environment}}$ and its impact on the $\mathrm{OWI}^{\mathrm{total}}$ (see Equation 2). Salinity was not measured at any farm, and WI input for salinity was based on each farmer's historical knowledge.

Although the observers carrying out the data recording were well acquainted with SWIM and the different WI (Welfare Indicator) levels, some ambiguity was experienced when scoring emaciation state, skin and fin condition. For emaciation state the observers discussed how strong the condition factor of the fish should be weighed versus the overall visual appearance, especially with regards to lean fish that otherwise looked healthy. For the WIs skin and fin condition, on some occasions it was questioned whether, in particular, scale loss (level 3; Table 2) and split fins (level 3; Table 2) were inflicted by netting when sampled. Due to uncertainty, it was decided not to discriminate between seemingly fresh damage and what appeared to have been inflicted previously.

Shortly after the first visit, all fish in farm F3 were slaughtered due to a government statutory order aiming to prevent the spread of salmonid alphavirus to the northern farming region of Norway. Accordingly, this farm was only visited once, leaving nine farms (18 cages) for the second visit. Due to technical breakdown of the weighing scale during the first visit on farm H3, only six fish were recorded for weight for cage b. In the two research farm sites (R1 and R2) group sizes had increased between visits by adding fish from neighbouring cages of the same origin that had undergone the same experimental treatment. Thus, we consider comparison of OWI score between visits still valid.

Fish size

During the first visit, the mean (± SD) fish weight measured during sampling was 238 (± 102) g (n = 20 fish per cage). In most cages this value was lower than estimated based on the feeding protocol in the farm management software (319 [± 166] g) (Figure 2). For the second visit, the average sample weight (1,103 [± 472] g) matched well with the average weight from the farm software estimates (1,089 [± 497] g) (Figure 2).

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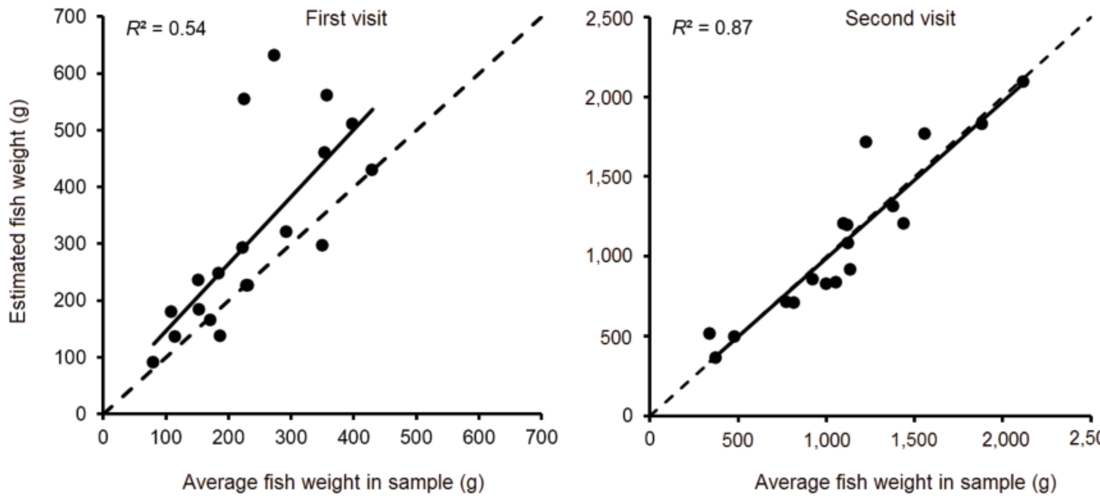
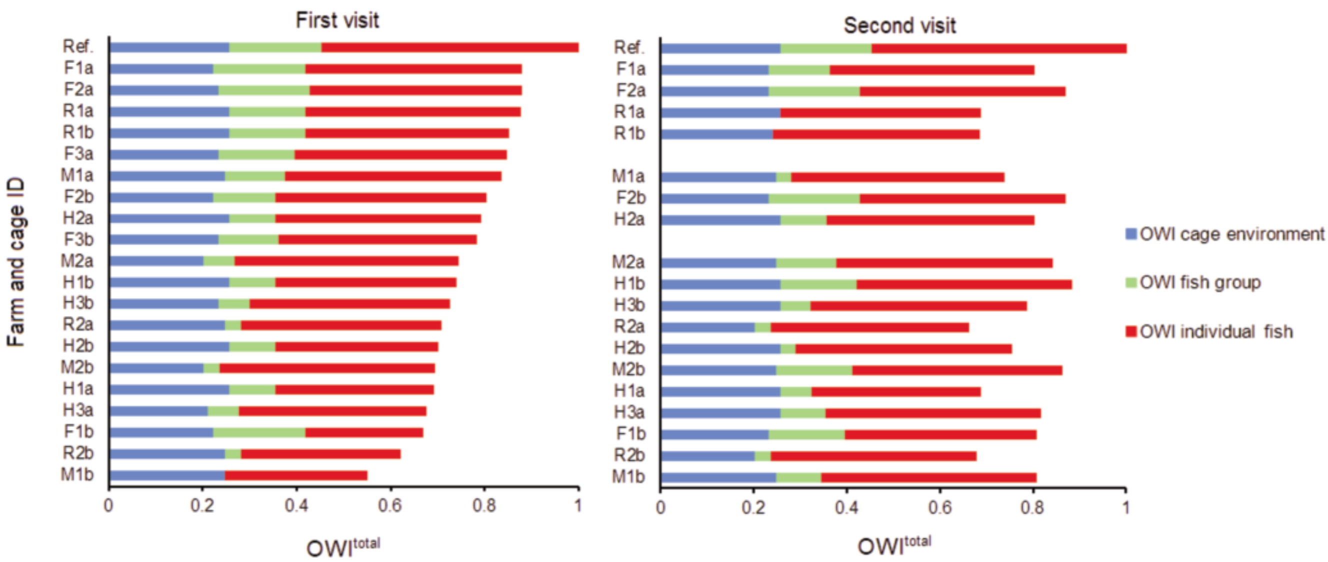
Figure 2



Comparison of fish weight (g) estimated by feeding tables and amount fed per cage at the different farms and average weight of the 20 fish sampled from the respective cages (note, different y-axis scale for the two panels). The full line indicates the linear trend for the estimated and sample weight relationship, and the dotted line indicates the 1:1 relationship.

Figure 3



OWI^{total} for the inspected sea cages showing the score for each specific OWI. The farms were visited twice, first during the summer 2012 (left panels), and secondly (right panels) 3–4 months later. The reference (Ref) bar indicates the best possible score per OWI (as shown in colour legends) which, in total, adds up to an OWI of 1 (best welfare). The respective cages are ranked from highest to lowest OWI total score for the first visit. Farms are coded for region (H: Hordaland; M: Møre and Romsdal; F: Finnmark) or farm type other than commercial (R: Research farm), farm number within region, and cage (a: best; b: worst cage at the farm as determined by the farmer at the first visit, see text for details).

OWI^{total}

The mean (± SEM) average OWI^{total} (range 0 to 1) for the first visit was 0.75 (± 0.02), ranging from a minimum of 0.55 to a maximum of 0.88 (Figures 1 and 3). At the second visit the average OWI^{total} had increased to 0.78 (± 0.02), ranging from a minimum of 0.66 to maximum of 0.88 (Figure 3). The research farms (R1 and R2) did not deviate from the commercial farms during the first visit (commercial average: 0.75 [± 0.22] vs research average: 0.76 [± 0.06]), but scored poorer at the second visit three months later (commercial average: 0.81 [± 0.15] vs research average: 0.68 [± 0.05]). For the commercial farms, the average score for all three component OWIs scored higher at the second visit, resulting in a significant increase for the OWI^{total} (0.07 [± 0.3], paired *t*-test, $t = 2.7$, df = 13; $P < 0.05$; Figure 1).

Comparing the best and worse (a and b) cages assigned by the farmer during the first visit, the average cage a OWI^{total} score of cage a for the first visit was 0.08 (± 0.03) higher than that of cage b (paired *t*-test, $t = 2.37$, df = 9; $P < 0.05$; Figure 4). This difference was caused predominately by component OWI$^{individual\ fish}$ (Figure 3). At the two farms (H1

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and H3) which showed a negative a and b relationship, the farmers were very tentative in assigning any difference, which was also the case for the research farms. Keeping the a and b assignment also for the second visit, the previous cage a vs b difference in OWI^{total} was no longer significant (0.03 [± 0.02], paired *t*-test, $t = 1.04$, df = 8; $P > 0.3$). In most cases, better farms scored relatively well for their 'worst' cage, considering the OWI^{total} score between cages (a and b) across the different farms (Figure 4).

OWI$^{cage\ environment}$

The median OWI$^{cage\ environment}$ score for the commercial cages was 0.90 (0.87, 0.97) (Q1, Q3) for the first visit and 0.96 (0.92, 1) for the second (Figure 5). The research farms did not differ from the commercial ones in water environment, but fish at farm R2 were topically deloused shortly before the second visit (level 3 for disturbance; Table 2) and the stocking density in cage R1b was sub-optimal (level 2; Table 2) as the fish were held in a 125 m^3 cage for a brief period. Differences between farms and visits were mainly attributed to whether operational procedures, such as topical delousing, had been carried out during the previous week, the presence of fresh/brackish water (fjord vs costal area) and regional differences in water temperature (colder in Finnmark).

OWI$^{fish\ group}$

The median OWI$^{fish\ group}$ score for the commercial cages was 0.5 (0.34, 0.71) (Q1, Q3) for the first visit, and 0.59 (0.38, 83) for the second. Research farm R2 showed high mortality and normal appetite at both visits, while farm R1 showed a marked reduction after experimental treatments (transport and starvation) as both cages scored zero for OWI$^{fish\ group}$ at the second visit.

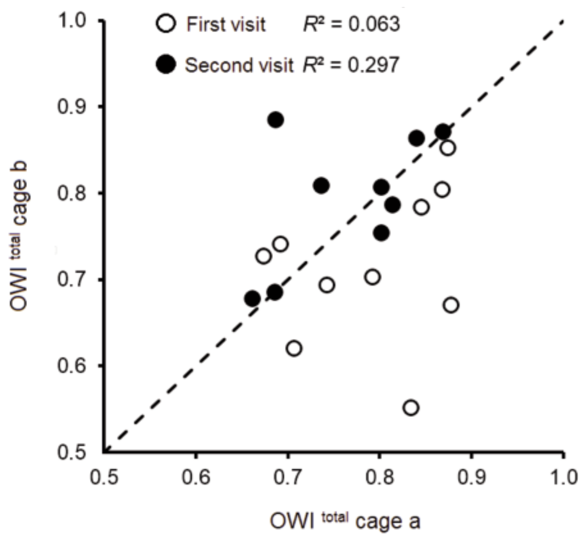
For the commercial cages, the median IS value for mortality (range 0 to 1) was 0.5 (at benchmark curve, level 3; Table 2) for the first visit, and slightly improved at the second visit (Table 3). The full range of mortality WI levels (except knockout) was represented at both visits (Figure 6). At cage level, the mortality score was, in most cases, not consistent between visits (Figure 6). The median IS value for appetite was 0.5 ('as expected', level 2; Table 2) at both visits, and 'poor appetite' (level 3; Table 2) was only assigned to one commercial cage (M1b, first visit; Figure 6). For the first visit 'good appetite' (level 1) was attributed to three of three cases which also had the best score for mortality, while the six observations of 'good appetite' at the second visit covered the whole mortality range (Figure 6).

OWI$^{individual\ fish}$

The top score for OWI$^{individual\ fish}$ was assigned to seven out of the 386 individuals sampled during the first visit, and none of the 360 individuals sampled during the second. By contrast, a minimum score was assigned to 21 and five individuals for the first and second visit, respectively. These fish were positively (clearly) emaciated (thin and assumed moribund fish), which is actually a knockout level for these individuals (OWI$^{individual\ fish}$ score of 0), indicating severely reduced welfare regardless of other WIs.

The mean (± SEM) OWI$^{individual\ fish}$ score for all sampled fish was 0.75 (± 0.01) (n = 386) for the first visit and 0.81 (± 0.006) (n = 360) for the second, showing less variation and improved OWI$^{individual\ fish}$ scores from the first to the second visit. The research fish did not score especially negatively for either visit compared to the commercial fish (Table 4, Figure 7), but did, however, show lower growth compared to fish in the commercial farms (Table 1).

Figure 4



Relationship between OWI^{total} for the two different cages per farm, ranked by the farmer as best (a) and worst (b) at the first visit. Dotted line indicates the 1:1 relationship.

Based on the average WI scores for the 20 sampled fish per cage (knockout values not applied), fin condition was the single WI that had the highest negative impact at both visits (Table 3), accounting for mean (± SEM) percentages of 45 (± 3) and 55 (± 2) of the total reduction in OWI$^{individual\ fish}$ for the first and second visit, respectively. Other WIs contributed less: skin condition (24 [± 2] and 30 [± 0.6]%), emaciation state (14 [± 3] and 3 [± 1]%), condition factor (10 [± 1] and 5 [± 1]%), and sea lice (7 [± 2] and 7 [± 2]%) (Figure 7, Table 3). For the remaining individual WIs, values other than the best scoring levels were only found in single individuals: one fish (farm R1) was sexually mature (level 3), one fish (farm H3) showed vertebral deformation (level 2), and one fish (farm M2) was poorly smoltified (level 3).

Fin condition

Most fins were porous, fragile, thickened and eroded, and based on the average values per cage (n = 20 fish), the mean (± SEM) proportion of fish showing fin condition at level 3 (ie moderate damage and split fins; Table 2) increased between the visits from 70 (± 4) to 94 (± 1)%, whereas the proportion assigned with level 4 (severe skin damage) decreased from 18 (± 4) to 4 (± 1)% (Figure 8). The proportion of fish with normal healthy fins (level 1; Table 2) decreased from 12 (± 3)% at the first visit to only three fish (< 1%) at the second (Figure 8). Fin condition at level 2 (scar tissue or slight necrosis) was only observed in one individual.

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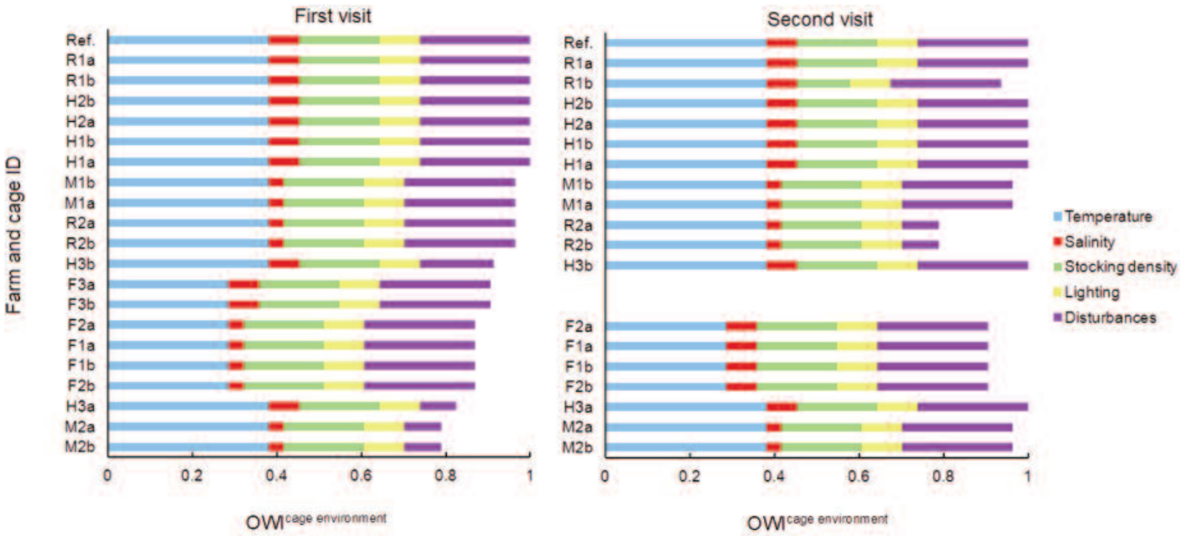
Figure 5



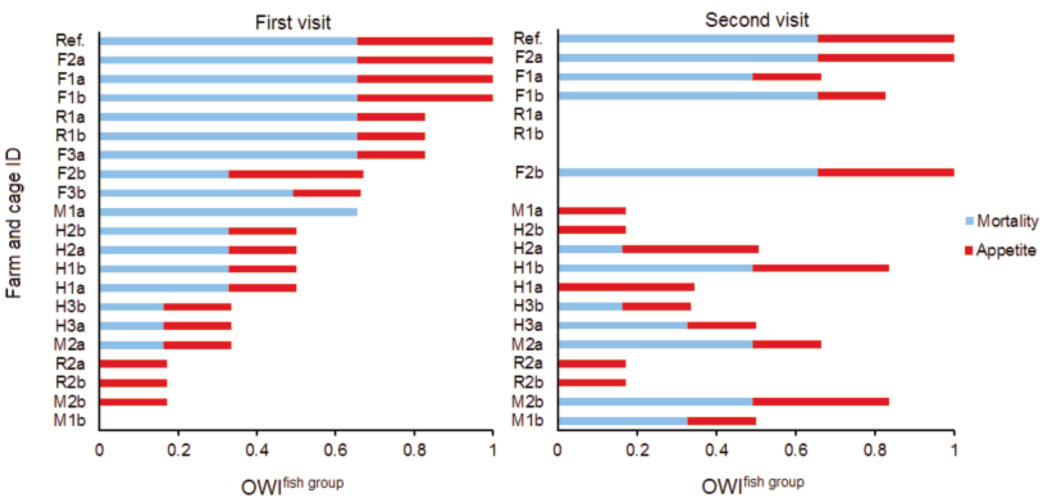
OWI$^{\text{cage environment}}$ for the inspected sea cages. The farms were visited twice, first during the summer 2012 (left panels), and secondly (right panels) 2–4 months later. The reference (Ref) bar indicates the best possible score per WI (as shown in colour legends) which in total adds up to a OWI$^{\text{cage environment}}$ of 1 (best welfare). The respective cages are ranked from highest to lowest OWI$^{\text{cage environment}}$ score for the first visit. Farms are coded for region (H: Hordaland; M: Møre and Romsdal; F: Finnmark) or farm type other than commercial (R: Research farm), farm number within region, and cage (a: best; b: worst cage at the farm as determined by the farmer at the first visit, see text for details).

Table 3 Mean (± SEM) values for cage environment, fish group, individual specific and total OWI (Overall Welfare Index, OWI range: 0 = worst to 1 = best) for eight different commercial farms (two cages per farm) for the first visit, and seven farms for the second.

OWI level	OWI weighting	First visit: mean (± SEM)	Second visit: mean (± SEM)	Paired t-test
OWI$^{\text{cage environment}}$	0.258	0.908 (± 0.018)	0.960 (± 0.011)	$P < 0.05$
OWI$^{\text{group}}$	0.196	0.566 (± 0.074)	0.597 (± 0.075)	$P > 0.5$
OWI$^{\text{individual}}$	0.546	0.742 (± 0.028)	0.812 (± 0.013)	$P < 0.05$
OWI$^{\text{total}}$	**1.000**	**0.750 (± 0.021)**	**0.808 (± 0.015)**	**$P < 0.05$**

The OWI$^{\text{individual fish}}$ calculations are based on average values of 20 individuals per cage. OWI weighting shows the relative impact of component OWIs for the OWI$^{\text{total score}}$.

Figure 6



OWI$^{\text{fish group}}$ for the inspected sea cages. The farms were visited twice, first during the summer 2012 (left panels), and secondly (right panels) 2–4 months later. The reference (Ref) bar indicates the best possible score per WI (as shown in colour legends) which in total adds up to a OWI$^{\text{fish group}}$ of 1 (best welfare). The respective cages are ranked from highest to lowest OWI$^{\text{fish group}}$ score for the first visit. Farms are coded for region (H: Hordaland; M: Møre and Romsdal; F: Finnmark) or farm type other than commercial (R: Research farm), farm number within region, and cage (a: best; b: worst cage at the farm as determined by the farmer at the first visit, see text for details).

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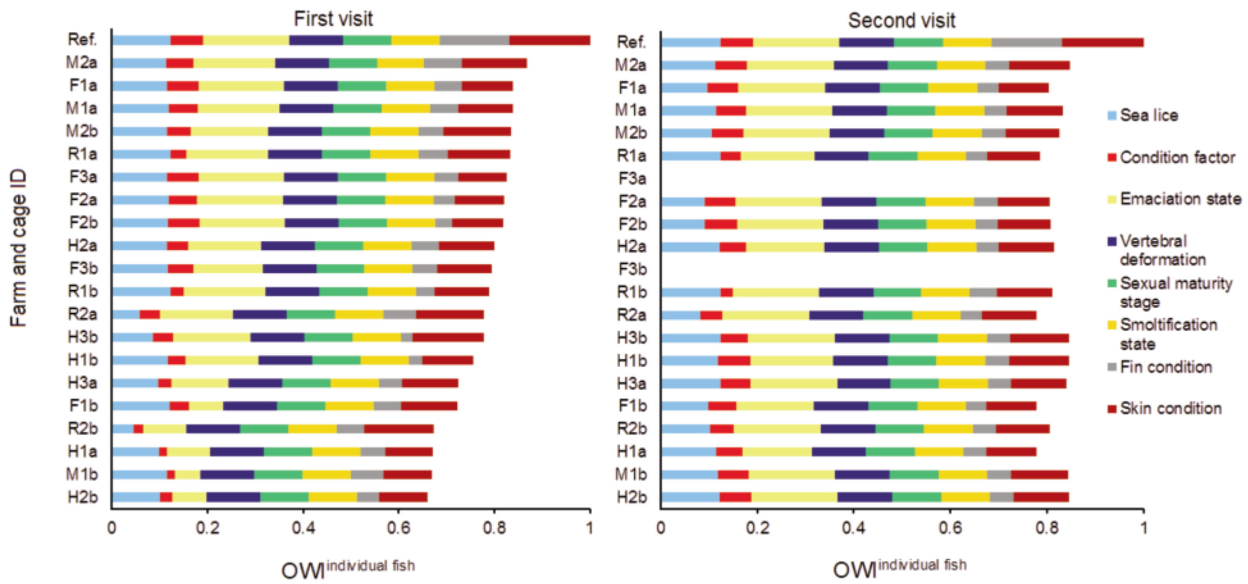
Table 4 Weighting factors for each welfare indicator.

OWI component	Welfare indicator	Weighting factor	RWF OWI^total	RWF component OWI	Median IS (Q_1, Q_3) first visit	Median IS (Q_1, Q_3) second visit
Cage environment	Temperature	16	0.098	0.381	1 (0.75, 1)	1 (0.81, 1)
Cage environment	Salinity	3	0.018	0.071	1 (0.5, 1)	1 (0.625, 1)
Cage environment	Stocking density	8	0.049	0.190	1 (1, 1)	1 (1, 1)
Cage environment	Lighting	4	0.025	0.095	1 (1, 1)	1 (1, 1)
Cage environment	Disturbances	11	0.067	0.262	1 (0.92, 1)	1 (1, 1)
Fish group	Mortality	21	0.129	0.656	0.5 (0.25, 1)	0.625 (0.25, 0.75)
Fish group	Appetite	11	0.067	0.344	0.5 (0.5, 0.625)	0.5 (0.5, 1)
Individual fish	Sea lice	11	0.067	0.124	0.93 (0.92, 0.95)	0.93 (0.69, 0.97)
Individual fish	Condition factor	6	0.037	0.067	0.7 (0.61, 0.89)	0.93 (0.85, 0.98)
Individual fish	Emaciation state	16	0.098	0.180	0.88 (0.81, 0.99)	1 (0.94, 1)
Individual fish	Vertebral deformation	10	0.061	0.112	1 (1, 1)	1 (1, 1)
Individual fish	Sexual maturation state	9	0.055	0.101	1 (1, 1)	1 (1, 1)
Individual fish	Smoltification state	9	0.055	0.101	1 (1, 1)	1 (1, 1)
Individual fish	Fin condition	13	0.080	0.146	0.35, (0.31, 0.38)	0.33 (0.32, 0.33)
Individual fish	Skin condition	15	0.092	0.169	0.66 (0.64, 0.7)	0.68 (0.63, 0.7)

In SWIM 1.0, WI, WIs of water current velocity and oxygen were excluded; Stien *et al* (2013). Included were relative weighting factor (RWF) for WIs relative to all recorded WIs (RWF OWI^total), RWF relative to each specific component OWI (cage environment, fish group and individual fish), median IS score (range 0–1) and first and third quartiles at cage level WI score for16 commercial salmon cages (14 cages for the second visit). For individual fish the scores are based on average score of 20 fish per cage.

Figure 7



OWI^individual fish for the inspected sea cages showing the average score for each welfare indicator (WI) based on a sample of 20 fish per cage. The farms were visited twice, first during the summer 2012 (left panels), and secondly (right panels) 2-4 months later. The reference (Ref) bar indicates the best possible score per WI (as shown in colour legends) which, in total, adds up to an OWI^individual fish of 1 (best welfare). The respective cages are ranked from highest to lowest OWI^individual fish score for the first visit. Farms are coded for region (H: Hordaland; M: Møre and Romsdal; F: Finnmark) or farm type other than commercial (R: Research farm), farm number within region, and cage (a: best; b: worst cage at the farm as determined by the farmer at the first visit, see text for details).

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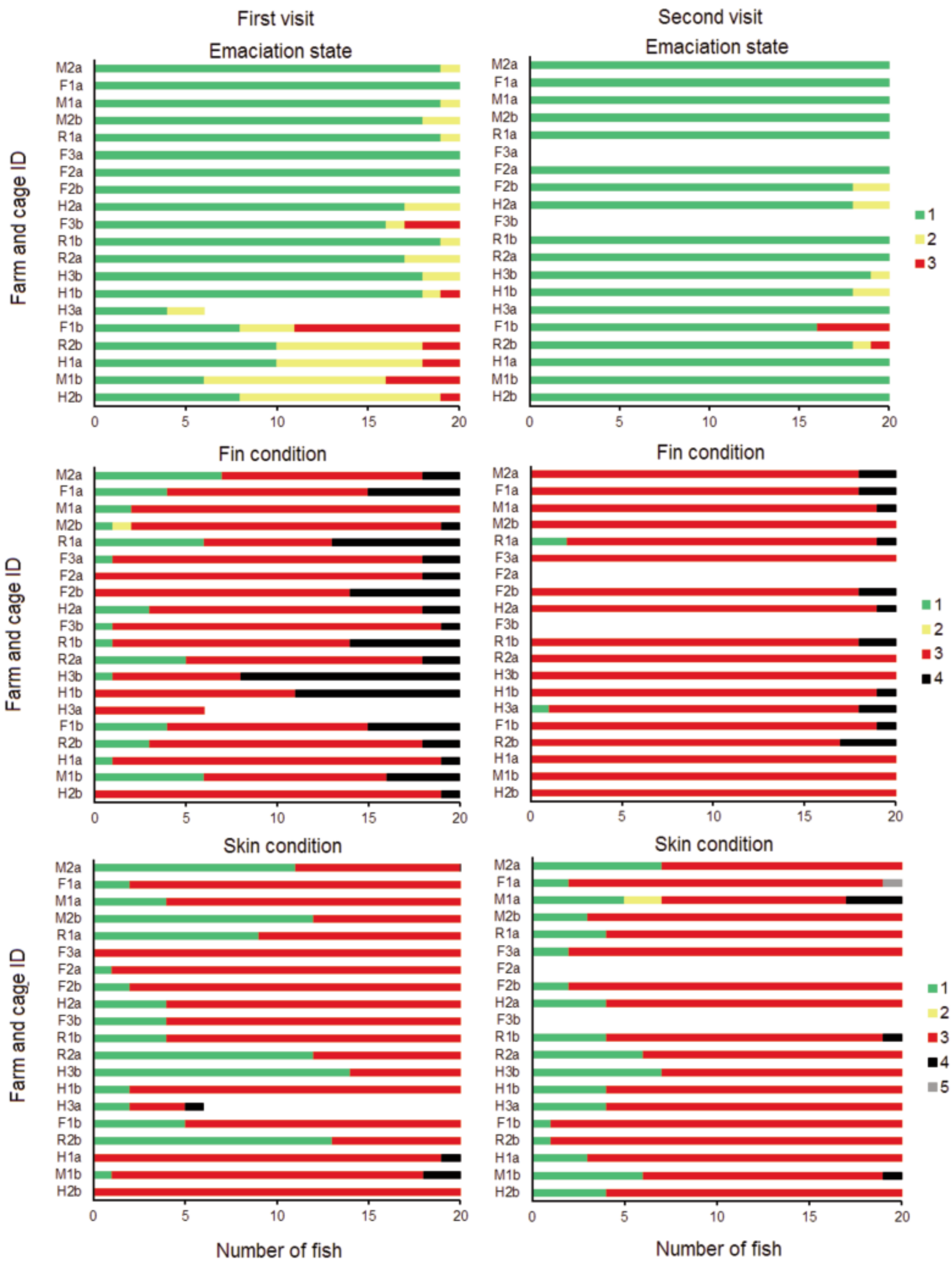
Figure 8



Number of individual salmon (20 fish per cage) scored with different levels of emaciation state (upper panels), fin condition (middle panels), and skin condition (lower panels). Levels are indicated with colour legends, where level 1 represents the best score (Table 2). The ranking is presented according to $OWI^{individual\ fish}$ as shown in Figure 4. The farms were visited twice, first during the summer 2012 (left panels), and secondly (right panels) 2–4 months later. Farms are coded for region (H: Hordaland; M: Møre and Romsdal; F: Finnmark) or farm type other than commercial (R: Research farm), farm number within region, and cage (a: best; b: worst cage at the farm as determined by the farmer at the first visit, see text for details).

Skin condition

The majority of the fish (70 [± 6] and 79 [± 3]% for the first and second visit, respectively) showed skin condition at level 3 (scale loss; Table 2), while only a few fish (four and six individuals) showed wounds or ulcers (level 4; Table 2, Figure 8). The proportion of fish with normal, healthy skin decreased from 26 (± 5) to 19 (± 2)% between the visits.

Condition factor (K)

As expected, the condition factor (K) increased with growth between the visits, where the per cage average for the commercial farms was 1.10 (± 0.01) for the first visit and 1.30 (± 0.01) for the second. The research fish showed a K cage average of 0.98 (± 0.02) for the first visit, and 1.04 (± 0.02) for the second, in line with less growth

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compared to the commercial fish (Table 1). For the commercial cages, the average cage level proportion of fish showing a normal *K* value (level 1, $K > 1.1$; Table 2) was for the first visit 54 (± 8)%, while 28 (± 4) and 19 (± 5)% showed a lower *K* at, respectively, levels 2 (*K*: 0.9–1.1) and 3 ($K < 0.9$). In comparison, 88 (± 2), 9 (± 2) and 4 (± 1)% scored, respectively, at level 1, 2 and 3 for the second visit.

Emaciation state

Emaciated fish were most numerous at the first visit (14 [± 4]% potentially emaciated and 5.3 [± 2]% positively emaciated) compared to the second visit (3 [± 1]% potentially emaciated and 1 [± 1]% positively emaciated; Figure 8). At the first visit, a large proportion (38%) of the positively emaciated fish showed a poor fin condition (level 4; Table 2) compared to potentially emaciated (18%) and normal fish (17%). The skin condition of potentially or positively emaciated fish was not more severe than normal fish (> level 3; Table 2), but fewer fish showed normal, healthy skin compared to normal fish; 5% (one fish) of the positively emaciated, 16% of the potentially emaciated, and 30% of the normal healthy fish. The mean (± SD) *K* of normal, healthy (not emaciated) fish was 1.23 (± 0.11) and 1.33 (± 0.16) for the first and second visit, respectively. For the first visit the *K*-value of potentially emaciated fish was 0.86 (± 0.12) and positively emaciated 0.89 (± 0.34), while it was 0.85 (± 0.22) and 0.74 (± 0.13) for the second. Most fish showing a normal *K* (> 1.1) were scored as not emaciated (98 and 99% match for the first and second visit, respectively), which was also true for fish showing a *K* between 0.9 and 1.1 (level 2) (89 and 90%) and for fish with *K* lower than 0.9 (level 3) for the second visit (69%). However, fish showing *K* lower than 0.9 for the first visit were more frequently scored as potentially emaciated (61%).

Sea lice

In most cages the sea lice infestation was absent or low, except in farm R2 (Figure 7) which was used in a study on the effects of infrequent delousing. In accordance with this, the fish in R2 showed extreme numbers of sea lice at the first visit (on average 24 lice per fish), but were subjected to topical delousing shortly before the second visit.

Discussion

The current testing suggests that it is feasible to conduct the SWIM 1.0 overall welfare assessment in salmon sea cages by using the recording premises of Norwegian salmon farms, and carry out the assessment within a reasonable amount of time. The recorded data and practical experience indicate a need for standardised sampling methods, further clarification of some Welfare Indicators (WIs), and emphasise the need for further scientific attention to other WIs, as will be discussed below. Moreover, a more user-friendly interface for registration is recommended to improve model precision and motivate users.

Model validation is inherently problematic, as no gold standard exists (Bracke *et al* 2002), and it is beyond the scope of the current study to discuss or conclude how well the actual welfare was reflected by the SWIM 1.0 model. The current sample design of two visits to the same farms did, however, allow checking for common factors over different cages and farms related to production period. Some WIs related to individual fish showed marked differences between visits; lower condition factor and relatively larger numbers of potentially and positively emaciated fish were sampled at the first compared to the second visit, and more homogeneous scores of moderate skin and fin damage were found on the second visit. This suggests that the model is suited to pick up important production stage-specific factors, where smolt quality problems commonly cause relatively high levels of emaciation and mortality during the initial months in sea cages (Soares *et al* 2011; Bleie & Skrudland 2014). Moreover, the model results were generally in accordance with the farmers' evaluation of within-farm best and worst sea cage. Both OWI$^{\text{fish group}}$ WIs of mortality and appetite were, however, also important in the farmers' evaluation of a best and worst cage, somewhat biasing our approach of contrasting within-farm cages. Still, the OWI$^{\text{individual fish}}$ was the most significant contributor for the best and worst cage difference. All in all, the present testing indicates that SWIM 1.0 is suited for its purpose.

OWI$^{\text{sea cage}}$

Oxygen levels were only recorded at two farms. However, at the recorded temperatures and fish stocking densities, oxygen is not expected to have been a limiting factor (see Stien *et al* 2013). As regards to temperature, most of the farms used single depth measurements (at 5-m depth) in what is potentially a stratified environment. Caged salmon position themselves according to vertical gradients of mainly temperature and light, and are attracted to the surface by feeding motivation/hunger and feeding (for a review, see Oppedal *et al* 2011a). Hence, single-point measures are not necessarily taken at the depth where most fish are positioned, and vertical environmental profiles of the cage depth should be preferably recorded. Pragmatically, the available measures at 5-m depth do, however, provide relevant information to detect critical conditions of high temperature and low oxygen levels (Oppedal *et al* 2011a,b).

OWI$^{\text{fish group}}$

The recorded mortalities covered the whole spectrum of the benchmark (Soares *et al* 2011) used in SWIM 1.0, indicating a relatively good match.

Appetite is based on the farmers' impression of relative food intake per cage (Stien *et al* 2013). Farmers adjust the feeding levels according to scientifically based feeding tables, size samples, and also by direct observations of fish appetite. None of the visited farmers used cameras to monitor feeding behaviour, suggesting that direct observation of fish was not highly prioritised, and several farmers were rather reluctant to classify appetite as normal or good. For the first visit most cages showed lower sample weight than the farm protocol estimate, suggesting an overestimation of biomass and, correspondingly, an underestimation of fish appetite. We recommend a clarification/more robust description of the appetite WI.

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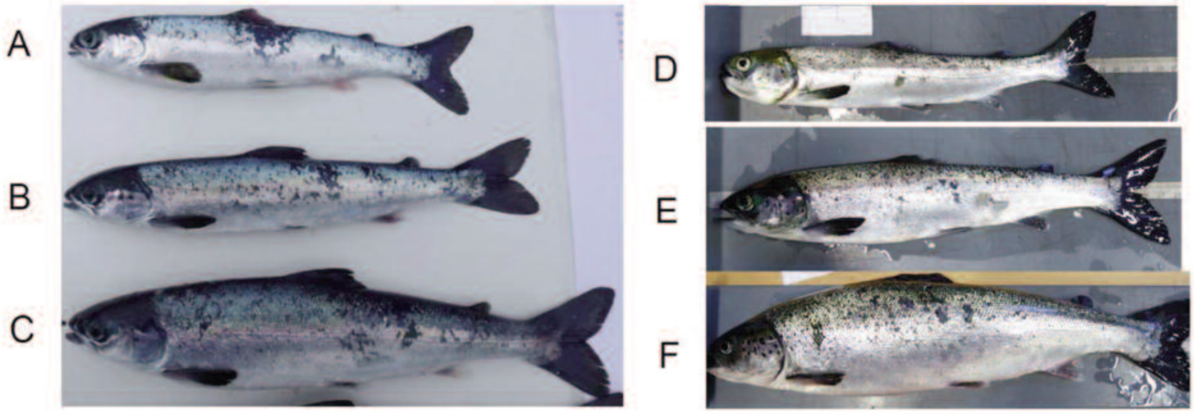
Figure 9



Scoring of emaciation states. A and B: fish scored as 'potentially emaciated' where fish B caused ambiguity if to be scored as 'positively emaciated' or not. C: Normal healthy fish from the same cage as fish A and B. Straightforward classification of emaciation state: D; positively emaciated fish, E; potentially emaciated fish, F; normal healthy fish.

OWI$^{\text{individual fish}}$

Welfare is experienced by individual fish and therefore the distribution and variation of the individual OWIs and the included WIs is of importance to our interpretation, not only the average OWI for the group.

Fin condition

There is, to our knowledge, limited information as to whether the high presence of fin damage and fin splits (70 and 94% for the first and second visit, respectively) is within the benchmark levels in Norwegian aquaculture. High stocking density has been suggested as a risk factor for fin damage (Turnbull *et al* 2005; Adams *et al* 2007), but in our trial, only cage R1b showed a reduction in the stocking density score.

Skin condition

The majority of the investigated fish (from 70 and 79% for the first and second visit, respectively) were assigned level 3, representing scale loss. Scale loss describes a loss of epidermis and, thus, for a shorter or longer period, a potentially dysfunctional skin barrier (Elliott 2011). Although the epidermis of fish is known to migrate rapidly (50–120 μm h^{-1} at 11°C; Hickey 1982; Andrews *et al* 2015), the size of the skin lesion is of major importance for welfare assessment (Bouck & Smith 1979). However, the levels did not distinguish between one or more scales lost, implying that one single scale loss may significantly reduce the skin condition score. This suggests development of (one or more) additional levels for skin condition. Two farms (H5 and M2) showed more than 50% healthy skin in both assessed cages at the first visit. The presence of such high values within farms, and lack of it in others can, however, not be related to stocking density (Turnbull *et al* 2005) or other information recorded in SWIM 1.0. The low number of fish detected with ulcers (four and six individuals for the first and second visit, respectively) may be associated with the low number of sea lice and, consequently, less delousing and handling procedures, and the time of the year for the visits (summer to autumn) (Coyne 2006; Noble *et al* 2012).

Emaciation state

In SWIM 1.0 emaciated fish are differentiated from behavioural abnormalities and are described as "generally small, very thin fish of poor health" (Stien *et al* 2013). Ambiguity regarding the scoring of emaciation state was particularly notable at the second visit to farm R1; the majority of the assessed individuals were lean (with a mean [± SEM] condition factor of 0.97 [± 0.03]) but showed no overt signs of poor health. The vast majority were scored as normal (level 1) for emaciation state. For all sampled fish, the within-fish match between level 1 (best score) for both emaciation state and condition factor was almost 1:1, but rather poor for levels 2 and 3, indicating that emaciation state functioned as a somewhat crude assessment of the general health status, rather than a score of thinness which the condition factor is an objective measure of. A higher proportion of severe fin damage (level 4) for individual fish that were scored as positively emaciated is in accordance with this. Fish that caused some debate as to whether they are assigned as 'positively emaciated' or 'potentially emaciated' are shown in Figure 9 (fish A and B, showing a condition factor [K] of 0.86 and 0.73, respectively), and are compared to the common size and physical appearance in the cage (fish C). Both fish A and B were classified as 'potentially emaciated'. Fish D, E and F in Figure 9 illustrate more clear (undisputed) examples of the three different emaciation levels.

The underlying causes of emaciation in farmed salmon, whether due to poor smoltification state/smolt quality (Bleie & Skrudland 2014), severe transportation stress (Iversen *et al* 2005), physical damage during handling and transport, pathogens, other factors, or a combination of several factors, are poorly understood and should be the subject of research. Pragmatically, the apparent physical state of what is considered here as emaciated fish, independent from underlying cause, is considered a viable indication of poor welfare.

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Condition factor

Only 54% of the sampled fish showed a condition factor (K) > 1.1 (best level) at the first visit, while the proportion was 88% at the second visit. This is in line with increased fat deposition with age/size (Solberg *et al* 2003) and the normal K around 1.0 in smolts (for a review, see Stien *et al* 2013). The reduction in condition factor for a large proportion of the fish scored during their first months in sea cages is a purely ontogenetic effect and may appear to be a contradiction to our current definition of welfare being "the quality of life as perceived by the animals themselves" (Stien *et al* 2013). The levels of the WI condition factor in the SWIM model should therefore be redefined so that fish size is taken into account.

Sea lice

Sea lice infestation was not a problem in 2012 for most areas visited. Farm R2 did, however, experience a high infestation pressure. The second visit to farm R2 took place shortly after topical delousing, where the potential reduction in OWI score given pre-delousing lice levels (level 3, farm information) corresponded to the reduction in OWI caused by the disturbance WI given the topical delousing (level 3; Table 2).

Practical considerations

The current time needed for carrying out SWIM 1.0 for two cages (approximately 1.5 h per farm) should be expected as a maximum (sampling 20 fish per cage). The data for $OWI^{fish\ group}$ and $OWI^{cage\ environment}$ related WIs were obtained from an interview with the farmer, and farmers sometimes had to search for the desired numbers/information. As little as 45 min should be needed when farmers with SWIM experience conduct the assessment themselves. Practically, SWIM may be carried out periodically (eg every month), in concert with the mandatory lice count which is conducted every week or every second week depending on the sea water temperature, above and below 4°C, respectively (Norwegian legislation). Periodic SWIM assessments are recommended in order to obtain the historical distribution of the welfare situation throughout the entire sea-cage production period. The currently observed changes in WI scores suggest that 2 to 3 months between SWIM assessments was insufficient to pick up important changes, at least in the early period in sea cages.

The currently used SWIM 1.0 sample size (n = 20) is debatable, and must be viewed as a trade-off between sample accuracy and precision, and the amount of time required. Importantly, the sampling method may significantly affect the required sample size. The sampling methods of fish in the current SWIM test varied from hand-feeding and manual netting of single or a few fish, to bigger catches by rapid winching of a big net, and netting from casting net hauls. Representative sampling and use of different sampling methods in sea cages is a recurrent topic of debate among farmers, veterinarians, researchers and governmental control groups, but there is sparse documentation regarding sampling accuracy and precision, and even less taking the objective of random selection into account. Some known factors are likely to influence the sample: size-dependent swimming depth in sea-caged salmon (Folkedal *et al* 2012; Nilsson *et al* 2013), highest sea lice infestation rate of salmon swimming near the surface (Hevrøy *et al* 2003), aggregation of chronically ill and moribund salmon close to surface and net wall (Stephen & Ribble 1995; O Folkedal, personal observations), and time of day with regard to hunger level/feeding motivation and surface attraction (Juell *et al* 1994). Validation of current sampling methods for welfare assessment, sample sizes and development of a common standard should be a priority of scientific research.

Taking into account that fish in the current samples were mostly caught at/near the surface (down to a depth of 2–3 m), we cannot rule out an over-representation of fish with relatively poor welfare (ie fish at the lower end of the size distribution, fish infested with lice and emaciated fish). For example, in cage F1a nine of 20 fish were positively emaciated at the first visit, while only one positively emaciated fish was found in the sample from this cage at the second visit, and the mortality between visits was 1.18% (0.023% per day). This suggests over-representation of emaciated fish in our sample or, in our opinion less likely, euthanasia of emaciated fish in the meantime or recovery of fish assessed as positively emaciated. The deviation between sample weight and estimated weight in farm F1a was, however, modest (–15%) compared to cages H1a (–59%) and H2b (–57%) which also showed high emaciation numbers in the sample at the first visit. The sampled fish at the second visit did, however, show a much better match with farm protocol estimates and fewer emaciated fish, suggesting that any sampling bias is markedly reduced after the initial months. The biomass control at cage level at the time of harvest is regarded as insufficient for the salmon industry as a whole (Aunsmo *et al* 2013), and hence the size estimations we attained from the different farmers may not accurately reflect the size distribution. The SWIM 1.0 model does, however, only rely on farm protocol estimates to calculate stocking density, but includes the bodyweight of sampled fish for recording of condition factor.

Several farmers expressed a degree of scepticism towards fish samplings that included small or emaciated fish. It is common practice for farmers to exclude such fish in lice counts and sample weighing as these will not be representative of fish to be processed and sold. However, excluding the poorest scoring fish cannot be justified in welfare assessment, where the worst fish in the cage should aid in understanding what is actually going on, and may function as 'ice-berg' indicators. The importance of a 'true' random sample should therefore be stated explicitly for the user.

The data storage/recording for the current swim assessment was carried out by filling out printed paper forms for later data entry into the SWIM online programme (http://www.imr.no/swim/index.htm). Practically, this allowed for a fast on-farm assessment, but may, however, be challenging for the novice SWIM user with regards to the levelling/scoring of WIs. As mentioned above, some confusion regarding levels was experienced, and a better description of levels is recommended. A future SWIM interface based on an application for computer tablets should reduce the need to rely upon printed paper forms and also provide the user with pictures/illustrations of the different levels to assist in the assessment.

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SWIM relative to fish growth

In the salmon industry, fish growth is the ultimate performance measure. In salmon, growth rate has been regarded as a solid operational welfare measure (Huntingford *et al* 2006), and must be viewed within the context of temperature (metabolic rate) and food availability. Nevertheless, growth has not been isolated as a WI in SWIM 1.0 as it was considered to affect several WIs (Stien *et al* 2013). In the current testing, the poor growth between visits to the research farms match their relatively poorer OWI score at the second visit compared with the commercial farms, indicating that SWIM 1.0 can 'pick up' attributes of growth.

Conclusion

The current evaluation of methods and results from deployment of SWIM 1.0 in Norwegian salmon farms suggests a promising model for commencement of overall welfare assessment of sea-caged salmon. This work can also be used as a first empirical step towards standardised monitoring and benchmarking of overall salmon welfare. Improved description of welfare indicator (WI) levels, including example pictures or illustrations, should further enhance the standardisation of SWIM and also motivate its use. We recognise sampling of fish as a challenge, as manifested by what we consider to be a potential over-representation of emaciated fish during some of the assessments carried out 2 to 3 months after transfer to sea cages. Scientific studies of manual sampling methods are needed to improve the basis for SWIM. Although the model is designed for use by fish farmers, we also encourage it as a tool to be further developed for potential future use by veterinary health professionals (SWIM 2.0) (Pettersen *et al* 2014) as well as the research environment. The model is flexible with regards to WIs to be included, and should be periodically updated based on novel scientific knowledge and user feedback.

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