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AQUATIC ECO-SYSTEMS

CASE STUDY

VALIDATION OF HIGH-ACCURACY OF BIOMASS ESTIMATOR FRAMES APPLIED TO THE PRODUCTION OF ATLANTIC SALMON (BIOMASS DAILY)

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INTRODUCTION

Salmon farming companies use different mathematical models to project the growth of the populations of their cultured fish. These models link the conversion of feed delivered with biomass or total weight increase, thus monitoring the growth of total fish biomass over time in the production farms (Brett and Grover, 1979; Aunsmo *et al.*, 2013).

Although the models link feed delivery to biomass growth (Jobling, 2003; Dumas *et al.*, 2010), they do not allow high accuracy growth predictions (Føre *et al.*, 2016), and the comparison of amount of feed delivered has a limited value when studying the growth of groups of unequal size or subjected to various abiotic factors (Aunsmo *et al.*, 2014).

Recent validation studies of growth models at semi-productive scale have indicated that daily weight gain is strongly associated with harvesting weights, but is considered inadequate to describe growth in Atlantic Salmon (Aunsmo *et al.*, 2014). On the other hand, the SGR was also associated with the size of the fish and it was observed that its calculation is skewed towards small fish when comparing fish of different sizes.

The TGC, SGR, and the EGI model were moderately associated with harvesting weights, and the same three models were more strongly associated with the average temperature and average daylight duration (Aunsmo *et al.*, 2014).

Studies on salmon growth published to date suggest that the robustness of current models used in aquaculture can be improved by taking into account nonlinear effects on growth and including abiotic factors such as temperature, light, and latitude (Aunsmo *et al.*, 2014). Recent scientific studies have shown that growth patterns for Atlantic Salmon (*Salmo salar* L.) tend to overestimate weight based on the food consumed (Føre *et al.*, 2016); and when there is a disease outbreak that affects fish conversion and growth, it cannot be corrected (Figure 1). This may lead to a loss of control of the real biomass with a subsequent loss of productivity (Føre *et al.*, 2016).

Based on the described background, to maintain an effective control of the production results, it is necessary to continuously adjust the mathematical projection models with the actual weights of the fish. This will allow the farmer to identify productive losses early during the cycle and not when it is too late to make decisions and take actions (Føre *et al.*, 2016).

Being aware that biomass control is a relevant issue to ensure high productivity levels (better growth, reduction of the FCR), a productive scale study was carried out in 2014 and 2015, where biomass estimators were used with the VAKI technology called Biomass Daily as an alternative method for estimating average live weights and frequency distributions.

The final objective of the study was to determine if it is feasible to replace the current scale sampling implemented in marine farming cages. Although this management practice is empirically validated by salmon farmers, it presents disadvantages of causing stress in the population when handling the fish, presenting in some cases percentage differences of up to 2 digits between the average weights and biomass reported by the salmon processing plants (López, Burgos and Ulloa, unpublished data).

OBJECTIVE, MATERIALS, AND METHOD

With the objective of validating the use of permanent frames as a reliable method for estimating the average weight of salmon during the growth months in sea pens, at Cultivos Yadran S.A., 4 biomass estimator frames were installed for a period of 14 months distributed in 4 cages of 30x30 meters of area. The research was carried out at an Atlantic Salmon (*Salmo salar* L.) post-smolts seawater farm in the Melinka area, Aysén Region, Chile. The site where the study took place was Rowlett 1 (Figure 2), which was selected especially for the years of experience of the Site Manager and his collaborators with the use of the biomass estimators.

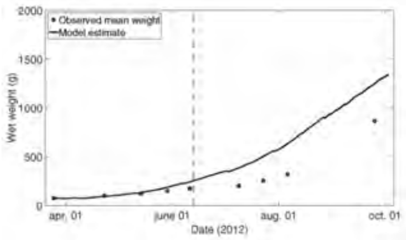

Figure 1. Comparison between the observed average weight of fish in a sea pen and the corresponding projection of the model. The black circles indicate weight measurements in the experiment, while the solid black line marks the model's estimate. The intermittent vertical line marks the approximate beginning of a Pancreas Disease (PD) outbreak that affected the salmon population.

Technological Equipment

The equipment used for the study was leased from VAKI (Figures 1 and 4), and consisted of 4 VAKI standard biomass estimators, 4 submerged cables, 4 holding ropes with a diameter of 12 mm and a length of 40 meters, 4 remote transmission antennas, one base antenna, and a CPU with the Bio-3000 software that manages the data generated by the frames. The system installed in each cage was powered by a 12-volt electric current for each of the frames and fed from the 220-volt power grid installed in central corridor of the sea pens.

Fish and Cages

Biomass estimators and data transmission antennas were installed in four cages holding approx. 50,000 fish each. Units 101, 102, 103, and 104 were selected from twentyfour cages that contained 1,200,000 Atlantic salmon smolts. The study covered a population of 202,897 fish that corresponded to 16.9% of the total fish population at the site.

Methodology

The research was carried out from the post-smolt stage until the harvest of the fish in each pen. The frames were installed once the smolts reached approximately 0.3 kg average weight and were kept in the same pen until an estimated harvest weight of 5.5 kg was achieved. The study was designed to monitor the average weight of the fish measured by the frames and compare it on a monthly basis with the average weight of the samples taken using a scale. In turn, the growth rates (SGR) obtained by the estimators and by the scale sampling were compared. The comparison of the average weight of the fish in each unit considered the weight differences in terms of grams and percentage.

From the beginning of the size estimation trial, a person was designated in charge of the estimator frames at the sea pens. The task was carried out by the Operations Assistant, a staff member of the site who was responsible for the movement of the frames for sampling purposes as well as for their cleaning and maintenance. The frames were placed underwater, anchored to a 12 milimeter rope and checked weekly for their depth localization in the pens (Figure 6).

RESULTS

Efficiency of operation and effectiveness of the VAKI frames.

From the start point of installation on May 14th, 2014, in general, the Biomass Daily system behaved in a stable manner regarding operation, and did not report frequent failures. The connectivity of the frames in the field performed without major problems and we were able to generate a stable data transmission from the equipment during the 14 months of use. The operating efficiency of the system during the study period is presented in Table 1.

The total valid measured fish from the four biomass estimators was 2,744,471 individual fish.

This result, from a data-generation perspective, exceeded the initial expectations and was largely due to the continued concern of the site operations assistants to correctly place the frames in terms of depth and horizontal location within the cages. The average measurements obtained with the frames were 1,620 fish daily, which was a high level of samples compared to measurements obtained with the same equipment in other sea farms or other biomass estimator systems (VAKI, 2016).

Figure 6. Standard location of the estimator frame in 30x30-meter square sea pens.

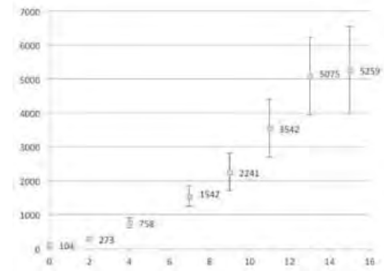

Figure 7. Growth pattern of the fish in pen 101 based on average weights and standard deviation obtained from the Biomass Daily frames. The X-axis represents the months that have elapsed since the entry of the fish (month 0) into the pen and the Y-axis represents the average weight of the samples expressed in grams.

Table 1. Functioning and operation of the biomass estimators during the period.

	EQUIPMENT CONNECTIVITY				USE OF EQUIPMENT		
CAGE NUMBER WITH FRAME	TOTAL NUMBER OF DAYS LEASED	NUMBER OF DAYS WITH CONNECTION	NUMBER OF DAYS WITHOUT CONNECTION	% OF DAYS WITH CONNECTION	NUMBER OF DAYS WITH FISH REGISTRATION	NUMBER OF DAYS WITHOUT FISH REGISTRATION	% OF DAYS WITH FISH REGISTRATION
101	413	384	29	93%	380	33	92%
102	431	395	36	92%	395	36	92%
103	421	386	35	92%	386	35	92%
104	433	368	65	85%	279	154	64%
AVERAGE	**425**	**383**	**41.25**	**90.5%**	**360**	**64.5**	**85%**

The amount of valid fish measurements achieved by the biomass estimators during the study is shown in Table 2.

Table 2. VAKI frame measurements in pens 101, 102, 103, and 104 in terms of average daily amount of fish measured and total valid samples during the 14 months of the study.

VALID MEASURED FISH		
PRODUCTION UNIT WITH FRAME	DAILY AVERAGE NUMBER	TOTAL NUMBER FOR STUDY PERIOD
101	1,865	770,498
102	1,814	782,162
103	1,682	708,162
104	1,117	483,610
	TOTAL NUMBER OF VALID SAMPLES	**2,744,471**

Average weight and cumulative growth rate of salmon during size estimation using Biomass Daily frames.

Since the installation of the frames at the second month after seawater-transfer of the smolts, we followed the average weights of the fish using the biomass estimators and compared them with their equivalent scale weight. At the end of the study, growth curves were generated for both biomass estimators and scales.

The deviations during the cycle between VAKI and scale were not statistically significant in terms of average weight, standard deviation of the samples, and growth rates (accumulated SGR) between the 4 pens studied (Figure 7 and Table 3).

Average weight and final number of fish (Final Biomass) in the processing plant of harvested fish compared to the scale sampling and sampling using Biomass Daily biomass estimators.

The final biomass received in the plant was 1,103 tons for the whole fish population included in the study. The final weight value from the processing plant for comparison with live weight of the frame and scale was obtained by dividing by 0,93 the net average weight of the fish in each pen, which represents 7% for factors such as bleeding, desquamation, and fasting (value widely used in the local salmon industry).

The differences of Final Biomass using the biomass estimator method and scale method were limited, but was greater in the case of scales sampling (Table 4). The total biomass of the fish in the 4 pens was slightly underestimated by both methods, with a 0.63% difference for the final biomass projected by scale (6.96 tons less) and 0.18% for the final biomass using VAKI (1.95 tons less) with respect to the final biomass registered in the processing plant.

The final fish biomass estimated by the frames before harvest, had a smaller deviation from the real biomass when compared to the final fish biomass registered by the manual sampling (Table 4).

The degree of accuracy of the 4 VAKI frames was acceptable and within the confidence ranges expected with respect to the average weight registered in the processing plant. The

Table 3. Size differences, average weight, standard deviation (SD) and accumulative specific growth rate (acc SGR) of Atlantic salmon smolts produced in pen 101 based on the data obtained from biomass estimator frames and manual sampling (scale) during the production cycle.

MONTH	SAMPLING DATE	SIZE VAKI (CM)	SIZE SCALE (CM)	AVERAGE WEIGHT VAKI (G)	AVERAGE WEIGHT SCALE (G)	SD VAKI (G)	SD SCALE (G)	ACC SGR VAKI (%)	ACC SGR SCALE (%)
2	June 7, 2014	29	29	273	297	48	44	1.53	1.67
4	August 26, 2014	40	42	758	747	143	111	1.39	1.38
7	November 14, 2014	49	50	1542	1570	294	251	1.21	1.22
9	January 14, 2015	55	58	2241	2408	547	500	1.06	1.09
11	March 27, 2015	64	63	3542	3758	850	661	0.99	1.01
13	May 31, 2015	71	72	5075	4875	1136	1125	0.92	0.91
15	July 1, 2015	72	—	5259	—	1270	—	0.87	—

average estimation error recorded by the 4 VAKI Biomass Daily frames was less than 3% (Table 5). The frame that had the smallest difference with respect to the average weight of the processing plant was located in pen 102, with a percentage difference of only 0,34% (-19 grams), equivalent to a degree of accuracy of 99.66%.

Table 4. Differences in the final fish biomass between biomass estimators and the weight data presented by the site using the FishTalk® software adjusted with scale sampling in the harvested production units.

PEN NUMBER	HARVEST DATE AT THE PEN	FINAL AVERAGE WEIGHT SCALE (G)	FINAL AVERAGE WEIGHT BIOMASS ESTIMATORS (G)	FINAL NUMBER OF FISH COUNT	FINAL BIOMASS SCALE (KG)	FINAL BIOMASS BIO-ESTIMATORS (KG)
101	01-07-2015	5358	5259	48,491	259,815	255,014
102	20-07-2015	5670	5605	46,271	262,357	259,349
103	13-07-2015	5496	5636	50,414	277,075	284,133
104	22-07-2015	5473	5579	54,337	297,386	303,146
FISH FINAL BIOMASS					**1,096,633**	**1,101,642**

The biomass estimator located in pen 101 recorded the lowest accuracy of the 4 frames, with a percentage error of 2,38% (-128 grams), compared to the processing plant weight, reaching a degree of certainty of 97.62%.

Table 5. Differences in grams, percentage difference, and degree of accuracy of the average weight estimate using biomass estimators compared to the final average weights of the harvested fish obtained in the processing plant.

PEN NUMBER	FINAL AVERAGE WEIGHT BIOMASS ESTIMATORS (G)	FINAL AVERAGE WEIGHT PLANT (G)	DIFFERENCE IN GRAMS VAKI - PLANT	PERCENTAGE DIFFERENCE (ERROR) VAKI - PLANT	DEGREE OF ACCURACY OF FRAME
101	5259	5387	-128	-2.38%	97.62%
102	5605	5624	-19	-0.34%	99.66%
103	5636	5602	+34	+0.66%	99.34%
104	5579	5516	+63	+1.32%	98.68%

The degree of accuracy in the average weight estimate for the frames located in all 4 pens under study was 98.83%, which represents a highly reliable result that validates the use of this technology in the production of Atlantic Salmon, and would justify the economic investment of the biomass estimators during the sea cycle. With this technology, the farmer can know with certainty the real fish biomass that is in the sea pens and will be able to adjust the feed to improve productivity, thus achieving a high degree of assertiveness in the real marketable biomass at the end of the cycle.

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This publication is a brief excerpt of the author's Master's thesis (in Spanish), whose complete work (other results and conclusions) will be available through the Faculty of Marine Sciences, Department of Aquaculture, Postgraduate Program of Universidad Católica del Norte, Chile.

BIOMASS ESTIMATORS PROJECTION

Today, salmon farming companies need a second alternative that they can use in addition to traditional sampling to estimate the weight of their fish populations (Lines & Frost, 1999). Current production software that projects growth and weights of salmon during the seawater cycle, while considering various factors in their mathematical models (historical data, sites, geographic area) must be permanently adjusted using a weight estimate to project with greater accuracy the real productive status of the fish populations. No matter what model is implemented, no single model will be able to predict or detect in time a reduction in the real growth rate of fish; e.g., a reduction caused by an outbreak of disease in the sea farm (Føre *et al.*, 2016).

From a productive and sanitary point of view, the main reason for replacing traditional scale sampling with biomass estimation technologies is to avoid stress and excessive manipulation of healthy fish so as not to affect their immune system (Barton and Iwama, 1991; Fast *et al.*, 2008), as well as to avoid the growth losses caused by fasting or food restriction days associated with the sampling operations (Reimers *et al.*, 1993; Einen *et al.*, 1998; Cook *et al.*, 2000; Johansen *et al.*, 2001), which can reach more than 30 days in total during a whole seawater production cycle.

Looking at the long-term future of aquaculture, as production cages become increasingly larger with larger populations of fish (Jensen *et al*., 2010), it is necessary to experiment with technologies that can form the basis for a future biomass measurement system capable of meeting industry requirements in terms of accuracy, reliability, and operational efficiency.

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