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Nofima
Norwegian Institute of Food, Fisheries and Aquaculture Research

Collection of feed spill and faeces from tank outlet

The FOGAS project

Illustration: Nofima

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See chapter 1

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Se kapittel 1

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1 Summary/recommendations

1.1 Summary/recommendations English

Feed spill collection and stripping of faeces are common tasks in fish nutritional trials at Nofima's Research Station for Sustainable Aquaculture at Sunndalsøra. The established method for collection of feed spill requires manual work and is time consuming. A simpler method for feed spill collection, which also allowed collection of faeces at the tank outlet, was developed. The result was a demonstrator denoted 'Spillbox'.

The Spillbox, with a vertical screen with horizontal wires, was placed at the tank outlet. Uneaten feed was collected in a container separated from the water flow. By using compressed air, faeces were collected in another container, also kept away from the outlet water. In the recovery test (n=4) with one feed, 87 % of the feed was collected.

Feeding salmon (biomass 46 kg) one diet containing Y_2O_3, faeces was collected for 24 hours, resulting in 31 g of faeces (mean, n=3). Apparent digestibility measured from faeces collected with the Spillbox resulted in very small variation among replicates, and digestibility of dry matter and energy was very similar to data obtained by stripping. The calculated digestibility of fat and nitrogen (protein) deviated from data obtained with stripping.

The Spillbox worked satisfactory for its purpose with the feed type used. For further documentation of the Spillbox for feed collection, testing with several pellet sizes and physical pellet qualities is required. For collection of faeces, it is recommended to investigate the deviation in AD values obtained with the Spillbox method and the stripping method.

Faeces quality varies with feed, and these initial tests indicated that the system may be controlled and adjusted for varying faeces qualities. However, a certain firmness of the faecal particles is required for collection with the Spillbox.

It is relevant to upscale and adapt the Spillbox for collection and reuse of uneaten feed, and collection of faecal matter (sludge) in commercial land-based salmon farming. Theoretic mass balance and amount of sludge produced in commercial farming in different situations was calculated.

In conclusion, the Spillbox could be used for collection of uneaten feed and for collection of faeces for digestibility measurements for the feed tested. Some optimization and adjustment of the system when used under different conditions, and documentation of its accuracy using several feed types is recommended.

1.2 Sammendrag/anbefalinger på norsk

Oppsamling av fôrspill og stryking av gjødsel er vanlige prosedyrer i ernæringsforsøk ved Nofimas Forskningsstasjon for bærekraftig akvakultur på Sunndalsøra. Den etablerte metoden for oppsamling av fôrspill er arbeids- og tidkrevende. I dette prosjektet ble det utviklet en enklere metode for oppsamling av fôrspill. Metoden gir også mulighet for oppsamling av gjødsel fra utløpet av karet. Resultat av prosjektet var en demonstrator som ble kalt 'Spillbox'. Navnet reflekterer at innretningen er formet som en boks, og den samler opp spillfôr, det er enkelt, og med unntak av 'x' er det likt på norsk og engelsk.

Spillbox'en baserer seg på en vertikal ramme med horisontale vaiere, kalt 'sprettrist', ved utløpet av karet. Fôrspill ble samlet i egen kontainer og dermed tatt ut av vannstrømmen. Ved hjelp av trykkluft ble gjødsel samlet i en annen kontainer, og tatt ut av vannstrømmen. En såkalt recovery-test (n=4) med ett fôr ga 87 % 'recovery'.

Laks (46 kg biomass) ble fôret et fôr tilsatt Y_2O_3 og gjødsel ble samlet over 24 timer. Dette ga i snitt 31 g faeces (n=3). Måling av fordøyelighet (‘apparent digestibility’, AD) fra gjødsel samlet med Spillbox’en ga svært like replikater og verdier for fordøyelighet av tørrstoff og energi avvek lite fra data beregnet ved stryking av gjødsel. For fett og nitrogen (protein) var det et avvik mellom verdiene for fordøyelighet målt fra gjødsel samlet med Spillbox og med stryking.

Spillbox’en fungerte tilfredsstillende med fôrtypen som ble brukt under testen. For videre testing av oppsamling av fôrspill med Spillbox’en, må det testes fôr med ulike pelletstørrelser og ulike tekniske kvaliteter. For oppsamling av faeces med Spillbox’en anbefales nærmere undersøkelser av avvik mellom verdier for fordøyelighet oppnådd med Spillbox-metoden og med stryking av gjødsel. Stabiliteten til gjødsel-partikler avhenger av fôret, og disse første testene tydet på at systemet kan styres og tilpasses til ulike gjødselkvaliteter. En viss fasthet av gjødselpartiklene er nødvendig for å samle disse med Spillbox’en.

Det er aktuelt å oppskalere og tilpasse Spillbox’en til bruk i kommersielle anlegg for å samle opp og separere uspist fôr og gjødsel. Teoretisk massebalanse for mengde slam i kommersielle anlegg ble beregnet.

Det ble konkludert med at med fôret som ble testet i dette prosjektet var Spillbox’en egnet til oppsamling av uspist fôr for måling av fôrinntak, og til oppsamling av gjødsel for måling av fordøyelighet. Det gjenstår optimalisering og tilpasning av systemet, og det anbefales å dokumentere nøyaktigheten ved måling av fôrinntak ved bruk av flere ulike fôrtyper.

2 Background

Feed spill collection and stripping of faeces are included in many of the fish nutritional trials run at Nofima's Research Station for Sustainable Aquaculture at Sunndalsøra. Feed spill collection, used for measurement of feed intake, is performed according to Helland et al. (1996). The method involves collection of particles in a wire mesh collector at the outlet of the tank. This is a mix of uneaten feed and faecal material, which have to be separated before the uneaten feed is weighed and dried. The content in the collectors is normally removed and weighed once daily. The method depends on a certain water stability of the feed pellets, and it consumes a noticeable amount of man hours in research projects. Collection of faeces is normally done by means of stripping according to Austreng (1978), and with the aim to measure digestibility of nutrients and energy in the feed. One limitation of this method is that digestibility is measured at one specific point of time. The stripping procedure must be included in the plan for the trial and may interfere with other samplings. A fish biomass of 15 kg or more is required to achieve the amount of faecal material required for chemical analysis of yttrium and proximate composition in one stripping.

Ideally, the uneaten feed and the faeces should be collected, separated from each other, and removed from the water. This should be achieved by using simple technology and minimal amount of man hours. Such a device will allow collection of feed and faeces with a minimal amount of work in fish trials.

In addition to this tool in fish trials, a device for effective collection of feed spill and faeces is highly relevant for land-based commercial farms. Currently, there is a need for improving methods for collection waste in commercial farms (Aas and Åsgård, 2019). If successful in small scale tanks used for research, the device may also be further developed into equipment used for collection of faeces and feed spill in commercial closed and semi-closed salmon farming.

The main aim of this project was to develop a method for automatic collection and separation of feed and faecal particles from tanks, independent of manual work, and with the accuracy and precision required for measurement of feed intake and digestibility in scientific studies.

3 Defining the main concept

Several different main approaches for collection of feed and faeces were considered. The original idea was to use swirl separators and develop a device within that would separate feed and faeces based on their different density and sinking velocity. But the sinking velocity may vary considerably among feed pellets. Besides, nutrients from both feed and faeces may dissolve in the water.

A devise where feed pellets and faeces are separated and kept out of the water was therefore preferred. The ideas developed and tested were based on this concept.

Another principle was to keep the system simple. From the start, use of compressed air or extra water pumps was therefore not tested. Extra equipment requires investments, space at each tank and maintenance. After testing several devices, however, use of compressed air was found necessary, and the final device depended on compressed air.

The priority of functions of the device were:

1. feed pellets collection with accuracy required for feed intake measurements in fish trials

2. reduce labour cost relative to accuracy

3. collection of faeces for digestibility measurements in fish trials

4. a device that can be further developed for collection of feed spill and faeces in commercials farms

4 The 'Spillbox' demonstrator

The result of the project was the demonstrator entitled 'Spillbox' (Figure 2). To collect feed of small pellet sizes, smaller openings between the wires were made compared to the previous prototypes. The frame for the wire, shown in Figure 1, was printed in plastic with 3D-printer. The wires were fixed with a metal blade.

The dimensions of the frame were:

Length:	14 cm
Width:	10 cm
Distance between wires:	2 mm
Width of slits for wire:	0.25 mm
Wire thickness:	0.25 mm

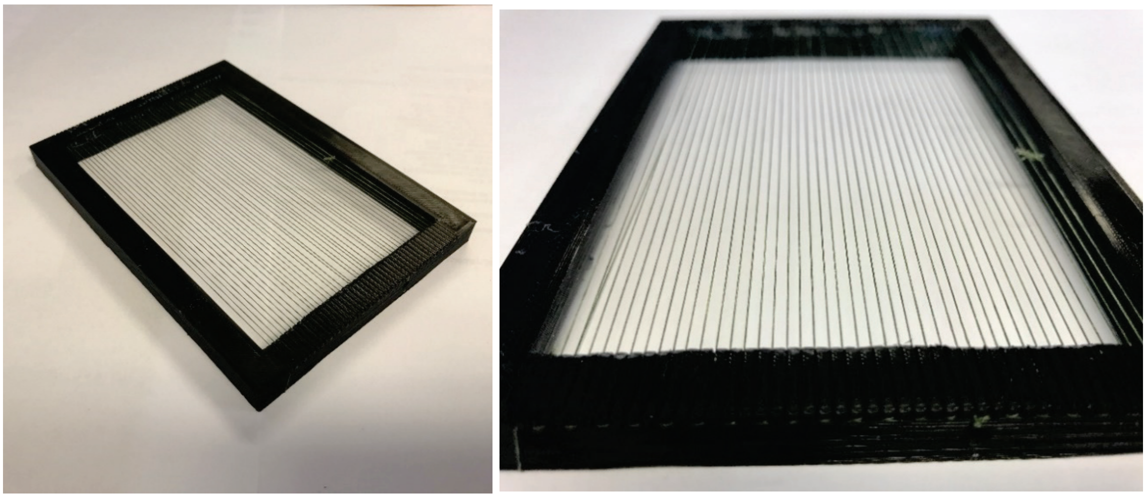

Figure 1 The frame with wire used for separation of water, uneaten feed, and faeces in the Spillbox

The final step was to collect faeces for digestibility measurements and to measure the recovery of feed spill ('recovery test'). To collect faecal samples for measurement of digestibility, the feed was changed from standard commercial 4 mm feed to a feed added yttrium oxide as a digestibility marker. The pellet size of the new feed was slightly smaller than the previously used feed, resulting in feed pellets passing through the wires of prototype no. 4. The new device was made with smaller spaces between.

The tube for compressed air was attached to the Spillbox with a Gorilla tripod intended for Gopro cameras. There was some movement of the tube when the compressed air started, and this was not as suitable as a permanent solution. For permanent use of the Spillbox, a steadier attachment of the air tube is required.

Figure 2 The Spillbox. Water from the outlet passes through the wires on the frame. Aided by the angle of the outlet tube, the pellets bump into the container on the left. The faeces stick to the wires on the frame and is blown into the container below by compressed air.

4.1 Testing the Spillbox – Recovery of feed

The recovery of uneaten feed was tested following the corresponding routines for recovery tests (Helland *et al.*, 1996) but using the Spillbox instead of the original containers. The test was carried out in one 1 m^2 fish tank n Hall 4 using a 4 mm test feed, and replicates were done as repeated measurements. The recovery test was done by feeding 300 g for 24 hours and was done in four replicates.

The collected feed contained 62.3 % dry matter and there was little variation among the four replicates (Table 1). With the currently used method for feed spill collection (Helland *et al.*, 1996), the collected feed spill may typically contain 45 % dry matter. This shows that the fast removal of feed spill from the water effectively reduces water absorption.

The mean recovery of feed when using the Spillbox was 87 %. For the recovery, there were some variation, one of the replicates deviating from the three others. The variation should be documented further, but these preliminary tests indicate that the Spillbox has potential for collecting uneaten feed and measure feed intake with high accuracy.

Table 1 Recovery test with the Spillbox, using a 4 mm test feed. Dry matter (%) of the collected feed, and recovery (%).

Replicate	Dry matter of collected feed	Recovery
1	63.5	92
2	62.3	86
3	60.7	85
4	62.6	87
Mean	62.3	87
Standard deviation	1.2	3
Coefficient of variation	1.9	3

4.2 Testing the Spillbox – Collection of faeces with the Spillbox

During the final testing of the Spillbox, the salmon was fed a test diet added Y_2O_3 used for measurement of apparent digestibility. Faeces was collected for 24 hours (repeated three times) from a 1 m^2 tank with 46 kg biomass salmon (47 individuals of mean weight 977 g). The faeces were collected during 24 hours in ambient temperature (approximately 11 ˚C, and after removal from the Spillbox, it was stored at -20 ˚C until chemical analysis.

On average, 31 g faeces ('as is') was collected in 24 hours from 46 kg biomass (Table 2). For analysis of yttrium and proximate composition of faeces, a minimum of 40 g of faeces may be required. Amount of faeces produced depends on feed intake in the fish. The dry matter content varies depending on feed and may often be in the range 10-15 %. This should be taken into account when estimating number of days of faeces collection when using the Spillbox in a fish trial.

Table 2 Faeces collection with the Spillbox over 24 hours in a 1 m2 tank with 46 kg biomass

Replicate	Amount of faeces collected in 24 hours (g)
1	26.9
2	31.6
3	35.2

The faeces collected during the final testing of the Spillbox produced long, sticky strings that stuck to the wires of the Spillbox to a larger extend than what was observed using the standard commercial feed. This challenge was overcome by increasing the intervals of compressed air. This shows that for each feed used in a fish trial, the system must be controlled, and it may be necessary to adjust the compressed air.

The feed used during collection of faeces was a fish meal-based test diet added Y_2O_3. The feed was formulated as 66.34 % fish meal, 15 % fish oil, 15 % wheat, 2.86 % vitamin mix, 0.04 % vitamin C, 0.72 % mineral mix and 0.020 % yttrium oxide.

4.3 Testing the Spillbox – Collection of faeces with stripping (for comparison)

After faeces was collected with the Spillbox, the salmon was stripped for faeces according to Austreng (1978) for comparison of digestibility measurements as a first step to evaluate faeces collection with the Spillbox. The faeces (a 178 g sample) were stored at -20 ˚C until chemical analysis.

4.4 Testing the Spillbox – measurement of apparent digestibility (AD)

AD measured with the Spillbox (triplicate samples) resulted in very good replicates (Table 3). The AD of dry matter and energy was similar to data obtained with the stripping method. The AD of nitrogen and fat deviated from values obtained with stripping. Faeces should be frozen instantly to avoid degradation, and the 24-hour collection period may have affected the results. Besides, method of faeces collection is known to affect the ADC results. If stripping is performed inaccurately, too much of the intestinal content may be collected, ADC may be underestimated. Urine may contaminate the sample and ADC of nitrogen is underestimated. Faeces collected by dissection may also collect too much chyme, resulting in underestimation of ADC. With methods based on collecting faeces from the water (Cho *et al.*, 1982, Choubert *et al.*, 1982), as is done with the Spillbox, material leaks to the water, which may bias the ADC.

Table 3. Apparent digestibility (%) of dry matter, fat, nitrogen and energy measured by collecting faeces by stripping (n=1) and by using the Spillbox (n=3).

	AD of dry matter	AD of fat	AD of nitrogen	AD of energy
Stripped faeces	66.3	89.6	81.0	79.2
Spillbox sample 1	67.3	80.7	83.8	79.1
Spillbox sample 2	67.2	81.1	83.7	78.7
Spillbox sample 3	67.6	80.1	84.3	79.3

5 Concluding remarks

A device for collection and separation of faeces and uneaten feed from the tank was developed. A simple method for collection without any extra equipment was desired, but this was not achieved, and compressed air was used to remove and collect faeces. Several prototypes and versions of these were tested. The final version, the Spillbox, worked satisfactorily under the conditions used during the preliminary tests for collection of uneaten feed.

For each new fish trial, the system must be controlled regarding satisfactory consistency of feed and faeces. Adjustment of the intervals with compressed air may be necessary.

Training of personnel is mandatory to achieve accurate data using the Spillbox.

5.1 Suggested further testing of the Spillbox

Before the Spillbox can be introduced as a standard equipment in scientific trials, more documentation is required. A thorough testing of the accuracy and precision of data acquired with this method should be carefully planned. These tests should include:

- Recovery tests for feeds with different pellet sizes
- Recovery tests for feeds with different physical properties
- Digestibility measurements, compared with results from today's method (Austreng, 1978) for feeds with different ingredients. The Spillbox is not suitable for collection of faeces from fish with diarrhoea.
- Compared to stripping of faeces, when the faeces are frozen immediately, faeces collected with the Spillbox is kept at ambient temperature during collection. Potential change in chemical composition should be examined.
- Recovery tests and digestibility measurements in tanks of different sizes and different water flows

5.2 Pros of the Spillbox

With the Spillbox, faeces and uneaten feed were quickly removed from the water. The method required far less man hours than today's feed spill collection. In a fish trial, the faeces can be collected in undisturbed fish and over a long period if desired when using the Spillbox. In many cases it will not be in conflict with other samplings in a fish trial with multiple measurements.

5.3 Cons of the Spillbox

The method will require manufacture of several units of the Spillbox, and investment, installation and maintenance of compressed air system at each tank.

5.4 Can the Spillbox' principle be used in commercial farms?

The principle of the Spillbox may be relevant to transfer to the scale used in commercial salmon farming. For collecting sludge solely, a simple version should be sufficient. The separation of faeces and uneaten feed in our tests indicates that it should also be possible to develop a system for reusing the collected feed. In today's land-based salmon farms, the sludge generally contains large amounts of feed spill, and the efficiency of collection of faces is moderate (Aas *et al.*, 2016, Ytrestøyl *et al.*, 2016, Aas and Åsgård, 2017, Aas and Åsgård, 2019). A further development based on the principle of the Spillbox may have potential for effective collection of faeces and for reuse of uneaten feed. If so, such new technology will have a large impact on feed utilization and on amount and composition of the sludge.

A further development of the Spillbox for use in commercial land-based farms may increase the efficiency of collection of uneaten feed and faeces compared to today's technology. The mass balance and the potential for collection of unutilized nutrients and energy (sludge) from land-based farms at different situations is shown in Chapter 6.

The Spillbox was developed and tested using small fish tanks (1 m^3) with low water flow (below 20 L/min) at Nofima's research facilities at Sunndalsøra. Tanks in a commercial land-based salmon farms are of a completely different scale. Upscaling of the Spillbox for use in commercial farms will require further development and optimization of the device.

5.5 Additional remark

After this project was finished, the optimization and refinement of the Spillbox and its function has continued. A patent was applied for (patent pending).

6 Modelling effects of feed spill with mass balances in aquaculture

6.1 General mass balance model

We used a mass balance to illustrate the effect of feed spill on solid waste production in aquaculture. Our model is calculated for a single tank of 500 m^3, stocked with Atlantic salmon smolts of 150 g at a density of 60 kg/m^3 (30 000 kg biomass). The model is based on the total feed input, digestibility and recovery of solid waste:

Solid waste collected = [feed consumed x (1 – digestibility) x faeces recovery] + (feed spilled x feed recovery)

Feed consumed and its composition and digestibility determine the amount and composition of faecal waste. Spill feed is determined by the economic FCR (feed conversion ratio) minus the biologic FCR. The recovery efficiencies of solid waste collection from faecal matter and spill feed determine how much of this waste can be separated from the effluent and collected for disposal and/or further valorisation. Unrecovered solid waste contributes to the organic load on a system and adds to the discharge of suspended/dissolved waste. The general parameters of the mass balance model are summarized in Table 3, the general digestibility model is presented in Table 4.

However, the recovery characteristics of feed pellets and faecal waste can have a profound effect on solid waste balances. A poor technical quality of feed pellets (e.g. due to ingredient choice or sub-optimal extrusion) can lead to the disintegration of feed in the system and subsequently hamper solid waste recovery. The same is true for the physical properties of faecal waste. Faecal pellets with low cohesion can partially disintegrate before they can be removed from the system, ultimately increasing the discharge of suspended/dissolved nutrients from a system. Low pellet quality can not only lower the recovery efficiency of feed and faeces in the system, but also hamper the settling/thickening process typically used to reduce sludge volumes before transport and disposal.

Therefore, we have calculated the effect of feed spill for two different scenarios to illustrate the potential impact of feed composition/quality on solids collection efficiency: Scenario A ("optimistic") illustrates the effect of a high-quality feed on waste recovery and scenario B shows the effect of low technical feed quality ("pessimistic") on the total waste recovery.

Between scenarios, only the parameters for solid waste collection efficiency have been changed to illustrate the potential effects of feed quality on solid waste collection. For each scenario, we have calculated five different cases of overfeeding, ranging from 0-45 % overfeeding. Feed intake remains constant between cases, to simulate the common practice of overfeeding in salmon husbandry. In operation, overfeeding has the purpose to ensure that feed intake does not limit growth. An overview of the differences between scenarios and cases is summarized in Table 5.

Endpoints for the mass balance model are the total amount of solid waste collected as dry matter, sludge volumes and heavy metal contents. The effect of overfeeding on the economical feed conversion ratio have been calculated as well to illustrate the penalty in efficiency of the overall production process.

Table 4 General parameters for fish and system in mass balance model, constant between scenarios and cases

Fish parameters	
Fish size	150 g
Feed conversion (biol.)	0.6 kg/kg
Growth rate (13°C)	2.1 % BW/d
Max. feed intake	1.26 % BW/d

System parameters	
Tank size	500 m^3
Stocking density	60 kg/m^3
Biomass	30 000 kg
Max. feed intake	378 kg/d

Table 5 Feed composition and digestibility, constant between scenarios and cases. Phosphorous, Cadmium and Zinc are part of the ash-fraction of feed and faeces.

	Feed digestibility & faeces composition ***[per kg of feed]***			
	Feed composition	**Digestibility**	**Faeces**	**Faeces composition** ***[per kg faeces]***
	g/kg	***%***	***g/kg***	***g/kg DW***
Moisture	50			
Protein	470	86	66	263
Lipids	240	92	19	77
Carbohydrates	170	40	102	408
Ash	70	10	63	252
Phosphorous	16.4	40	9.84	39.4
Cadmium	0.000323	0	0.000323	0.00129
Zinc	0.17	30	0.12	0.47
Dry matter (total)	950	73.7	250	1000

Table 6 Overview on scenarios and cases calculated in mass balance model. System parameters, feed load, intake and digestibility are constant across all scenarios and cases.

	Scenario A **High-quality feed** **"Optimistic"**	**Scenario B** **Low quality feed** **"Pessimistic"**
Faeces collection efficiency	65 %	50 %
Feed spill collection efficiency	90 %	60 %
Dry matter content faecal waste	15 %	15 %
Dry matter content feed spill	90 %	80 %
Feed spill/overfeeding for each scenario	0 %, 5 %, 15 %, 30 %, 45 %	

6.2 Results

With overfeeding, the economic feed conversion ratio of an aquaculture operation increases, as less feed is converted into fish biomass (Table 6). At 45 % overfeeding, the economic feed conversion is 45 % higher than if zero feed is spilled. As expected, overfeeding has a tremendous impact on the overall production of solid waste. Depending on feed spill and recovery efficiency, the daily dry matter collection ranges from 47 to 215 kg of dry matter/day in a tank of 500 m^3 (or about 0.3-0.6 m^3 of settled sludge per day). At 45 % overfeeding, the solid waste production is about 3.1-3.5 times higher than if no feed is spilled (Figure 3).

For a high-quality feed with good recovery characteristics for feed and faeces, the amount of sludge produced with an overfeeding percentage of 15 % is almost double of the sludge collected with zero feed spill (45 % in scenario A vs. 42 % in scenario B). However, the overall solid waste production is lower for a low-quality feed (B) than for a high-quality feed (A) (81 kg DM/d and 112 kg DM/d, respectively). At 15 % overfeeding and a low-quality feed, about 28 % of solids would not be recovered when compared to a high-quality feed at equal overfeeding. Since the solids are not retained, the organic load and nutrient discharge from systems with low quality feeds would increase substantially.

Furthermore, feed spill has also an exceptionally negative effect on the phosphorous balance. At 45 % overfeeding, the amount of phosphorous waste is doubled. Although feed spill will also increase the absolute amounts of heavy metals collected as solid waste, their respective concentrations in the solids will decrease as more feed is spilled. At 45 % overfeeding, the concentration of Cadmium in solid waste is cut in half compared to zero feed spill. Thus, avoiding feed spill can have a seemingly negative effect on heavy metal concentrations on solid waste, even if the total amount of collected heavy metals is higher.

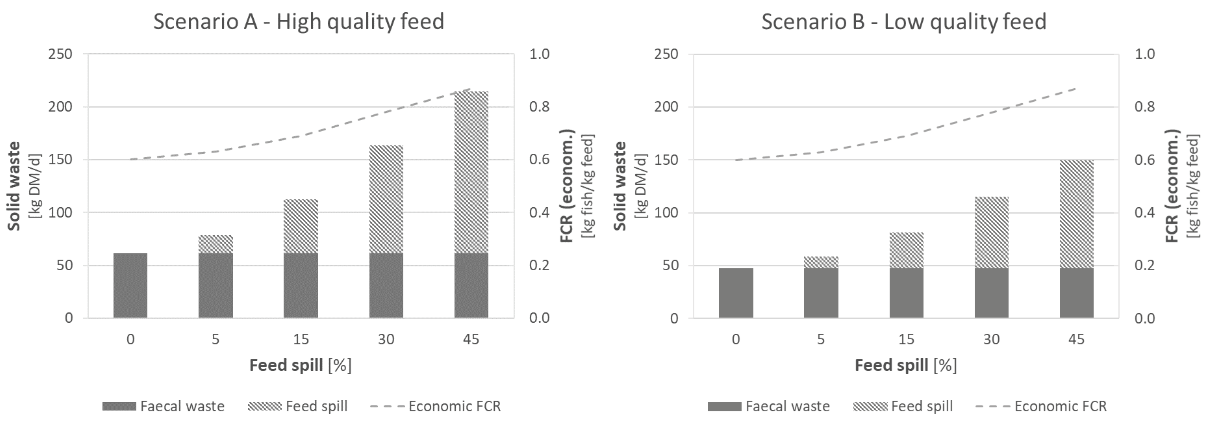

Figure 3 Waste production and economic FCR for a high and a low technical quality of feed, calculated for overfeeding rates of 0-45 %.

The waste material (faeces and feed spill) not collected as sludge will be released with the outlet water from the system. In the overall mass balance, this corresponds to the difference between 100 % and the collection efficiencies for faeces and feed spill used for the calculations, see Table 5. In scenario A Figure 3, Table 5), the amount of dry matter not collected will be 33 kg at 0 feed spill, and 50 kg at 45 % feed spill. In scenario B the amount of dry matter not collected will increase from 47 kg at 0 feed spill to 115 kg at 45 % feed spill.

Table 7 Mass balance calculation for feed and sludge from a high and a low technical quality of feed, including different overfeeding percentages. Amounts retained in fish or lost to the environment are not shown.

	Unit	Scenario A - High quality feed ("Optimistic")					Scenario B - Low quality feed ("Pessimistic")				
Overfeeding %	%	0 %	5 %	15 %	30 %	45 %	0 %	5 %	15 %	30 %	45 %
Effects on operation											
Daily feed load	*kg feed/d*	378	397	435	491	548	378	397	435	491	548
Daily feed spill	*kg feed/d*	0	19	57	113	170	0	19	57	113	170
Economic FCR	*kg/kg*	0.60	0.63	0.69	0.78	0.87	0.60	0.63	0.69	0.78	0.87
Total solid waste collected	*kg DM/d*	61	78	112	163	215	47	59	81	115	149
Feed spill in solid waste	*%*	0	22	45	62	71	0	19	42	59	68
Settled sludge volume	*m^3/d*	0.41	0.43	0.47	0.52	0.58	0.32	0.33	0.36	0.40	0.44
Sludge DM content	*%*	15	18	24	31	37	15	18	23	29	34
Phosphorous											
Total amount	*g/d*	2418	2697	3255	4091	4928	1860	2046	2418	2976	3534
Concentration, DM	*g/kg DM*	39.4	34.4	28.9	25.0	23.0	39.4	34.9	29.7	25.8	23.7
Concentration, Sludge	*g/L*	5.9	6.3	7.0	7.8	8.5	5.9	6.2	6.8	7.4	8.0
Cadmium											
Total amount	*mg/d*	79	85	96	112	129	61	65	72	83	94
Concentration, DM	*mg/kg DM*	1.29	1.08	0.85	0.69	0.60	1.29	1.10	0.89	0.72	0.63
Concentration, Sludge	*mg/L*	0.19	0.20	0.21	0.21	0.22	0.19	0.20	0.20	0.21	0.21
Zinc											
Total amount	*g/d*	29	31	37	46	54	22	24	28	33	39
Concentration, DM	*g/kg DM*	0.47	0.40	0.33	0.28	0.25	0.47	0.41	0.34	0.29	0.26
Concentration, Sludge	*g/L*	0.07	0.07	0.08	0.09	0.09	0.07	0.07	0.08	0.08	0.09

6.3 Controlling solid waste production by controlling feed spill

In this report, we also want to highlight that waste management in aquaculture is an integrated process that starts with feed and feeding. To reduce nutrient emissions, the conversion of feed into fish biomass must be maximized. The overall efficiency of waste reduction can be improved by increasing the digestibility of nutrients from feed ingredients, balancing nutrients according to requirements, improving the technical feed quality and adapting the faecal matter consistency for the solid waste removal. Reducing feed spill and using feeds with good nutritional and physical properties will reduce solid and dissolved waste production. An efficient removal of solid waste subsequently reduces the need for dissolved waste treatment. Thus, the development of better feeds and the reduction of feed spill are vital tools to reduce the environmental impact of aquaculture.

Overfeeding is common practice in salmon husbandry to ensure that feed intake is not limiting growth of the fish. However, the spilled feed has a large impact on the amounts of solid waste produced. An overfeeding rate of 15 % would almost double the solid waste output from a farm. Feed currently accounts for about 50 % of the production cost of salmon from egg to harvest size and the collection, thickening and the disposal of sludge is a costly process. Thus, feed spill should be avoided whenever possible, not only to reduce environmental impacts, but also to increase the economic efficiency of a farming operation. A feeding system that ensures full voluntary feed intake but avoids feed spill is needed.

Avoiding feed spill is not trivial, since a too restrictive feeding regime might result in sub-optimal fish growth and/or a larger spread in size distribution. The key to knowing how much feed that is enough and how much is too much, is the accurate monitoring of feed spill. Systems for feed spill monitoring are available for sea cages, but land-based systems offer a different set of challenges due to generally smaller production units and highly concentrated effluents where feed and faeces are mixed.

The FOGAS project aims to provide a simple, cheap and scalable solution to separate feed spill from faecal waste specifically for land-based systems. Although the collection of feed spill by itself does not reduce overall amounts or volumes of sludge produced in a fish farming operation, the immediate separation of feed spill from faecal waste offers several advantages over the conventional approach of a mixed waste stream.

First and foremost, the separated feed spill can be used to assess the feed intake of each tank individually and adjust the feed load accordingly to reduce feed wastage and overall solid waste production. The immediate removal of feed spill also reduces the potential of pellets disintegrating and leaching nutrients into the water. Reducing the leaching of nutrients into the water improves water quality, biofilter performance and reduces dissolved waste emissions from land-based systems.

Separating feed spill in a readily accessible side-stream offers several advantages for solid waste management. Having access to well-defined solid waste streams (feed waste and faecal waste) can help to develop a better waste management concept, where different streams can be valorised more efficiently (e.g. faeces for land application and feed for recycling). Furthermore, the collected feed spill has a higher dry matter content and stability than faecal waste and can be dewatered with less effort than a mixed sludge with faecal waste. However, the separation of feed spill from faecal waste will also change the composition and properties of sludge. If only faecal waste is collected, the concentration of heavy metals might increase. Although the overall mass balance might not change, this increase in concentration could cause problems where strict concentration limits for the re-use of disposal of solid waste apply.

To control dissolved waste emissions, it is also important to consider the water stability of feed pellets. Although the disintegration of low-quality feed pellets will lower the total amount of solid waste produced in a system, the unrecovered solids will increase dissolved waste emissions and the organic load in land-based systems.

Depending on the quality of the collected feed pellets, even the re-use of feed in production could be considered. If feed spill can be accurately monitored and collected in operation, a combination of adjusting feed load according to feed intake and the reuse of feed spill could help to develop production systems with close to zero feed spill.

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