

Smolt production and the potential for solid waste collection in Norway

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Report

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<i>Summary/recommendation:</i> The yearly production of smolts in Norway tripled since 2000, to about 344 million individuals Norway in 2018. Although Nordland accounts for only 13 % of companies and 16 % licences, 30 % of all smolts were produced there. The number of licences and companies producing smolts has been steadily decreasing over the last years, while smolt production was increasing. This indicates that the industry is consolidating and becoming more centralized. We estimate that a total of approximately 8 000 tons of solids have been produced as dry matter in Norway in 2017. This translates to about 54 000 T of sludge with a dry matter content of 15 %. It is not clear how much of this resource is readily available for collection or commercial exploitation, since effluent treatment is not always required. However, the increasing use of large-scale RAS such as the system of Fredrikstad Seafoods can offer a readily accessible waste stream due to the separation of solids in operation. Considering that waste volumes will increase while the industry consolidates, it will become more likely that centralized solid waste valorisation processes will become not only feasible but also profitable through economy of scale.	<i>Project No.:</i> 12725
<i>Summary/recommendation in Norwegian:</i> Den årlige produksjonen av smolt i Norge er tredoblet siden år 2000 til 344 millioner smolt i Norge i 2018. Nordland er den største produsenten med ca. 30 % av den totale smoltproduksjonen. Vi anslår at ca. 8 000 tonn avfallsstoffer har blitt produsert som tørrstoff i Norge i 2017. Med tanke på at avfallsmengder vil øke mens næringen konsoliderer, vil det bli mer sannsynlig at sentralisert valorisasjon ikke bare vil bli gjennomført, men også lønnsomt gjennom storskala driftsfordeler.	

Preface

Nofima was approached by Biogas Oslofjord about the potential of using solid waste from smolt facilities in Norway to produce biogas. To assess the valorisation potential of solid waste produced in Norwegian smolt farms, it is necessary to understand the structure and the production capacities of the Norwegian smolt industry. Within the framework of this project, Nofima was tasked to provide a brief overview on the total number, production volumes and geographic distribution of smolt farms in Norway. Based on the collected data, we estimate the growth potential of the sector and provide qualitative information about solid waste production waste and waste treatment potential in the smolt farms of Norway.

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1 Introduction

In 2017, Norway supplied over half to the global salmon production and almost 1.3 million tonnes of salmon were sold at value of around 65 billion NOK in 2018 (Ernest and Young, 2018; Miljodirektoratet, 2019). The Norwegian seafood industry has set the goal to produce of 5 million tonnes of seafood in Norway by 2050 (Sjømat Norge, 2018). This ambitious goal entails roughly a five-fold increase of current production volumes (NRK, 2019). Currently, salmon accounts for about 95 % of the aquaculture production and for 68 % of the export value in seafood (Miljodirektoratet, 2019; NRK, 2019). Therefore, a rapid expansion of the Norwegian salmon sector is instrumental to realize this objective by 2050. Norway has acknowledged the need for sustainable growth and incorporated UN Sustainable Development Goals in its strategy for the development of the industry.

To realize this production goal, the industry relies on the supply of salmon smolts for grow-out. Although the final grow-out of salmon is happening mostly in sea cages, these cages must be stocked with smolts from land-based production systems. As production capacities increase, the production of smolt has to be increased as well to supply the demand for fish to stock grow-out systems. Consequently, more waste will be produced in land-based systems and a suitable waste management strategy is required to ensure a sustainable expansion of the Norwegian salmon industry.

To manage waste emissions, the first and most important step is to remove solid waste (e.g. faecal waste or spilled feed) from the farm effluent before it is discharged. These residual solids can be removed from the water by either sedimentation or microscreen filtration (Cripps and Bergheim, 2000). In practice, drum filters are often used for an efficient collection of solids from the large and dilute flows typical for fish farms. The collected solids are rich in organic and inorganic nutrients and should thus not only be considered as a nuisance, but as a valuable resource. Traditionally, sludge from fish farms has been used as a fertilizer in agricultural land application (Cripps and Bergheim, 2000). As production capacities are increasing and the concentration of solid waste is becoming more cost-efficient, industrial valorisation processes such as the production of biogas or fertilizer are becoming feasible (Tekfisk, 2018; SalmonBusiness, 2019).

The goal of this report is to provide an overview on the structure and geographic distribution of the Norwegian smolt production industry and to estimate the potential solid waste production. We have analysed data from the Norwegian Directorate of Fisheries for the number of companies, production licences and the number of smolt produced in different geographic areas. Based on the collected information, we estimate feed consumption and potential waste production in Norwegian smolt farms. A brief overview on common solid waste treatment strategies will provide background information on how solids can be concentrated for further potential valorisation.

2 Data collection and analysis

Unless explicitly stated, all data concerning smolt production, licences and companies has been collected using the openly available data provided by the Norwegian Directorate of Fisheries (Fiskeridirektoratet). In this report, smolt always refers to smolts of the Atlantic Salmon (*Salmo salar*, L., 1758), the by far most relevant species in Norwegian aquaculture production. Although the data for 2018 concerning the number of licences, companies and individuals is preliminary, we have included it in our analysis. No substantial changes in numbers are expected and historical trends correspond well to the data of 2018.

Using a mass balance approach, we can estimate the waste production based on feed load (Roque D'Orbcastel *et al.*, 2008). To estimate the feed load, we have used the average feed costs for smolt production from Fiskeridirektoratet. Waste production is then determined by taking the number of individuals, estimated feed load and digestibility-based waste production into account. For estimating smolt production and waste loads in average and large smolt farms, we have used the latest dataset of licences from the *Akvakulturregisteret*¹ and filtered for the relevant data as described later.

An acceptable estimate for solid waste production in salmon production is 150 g of solid waste as dry matter per kg of feed (Bjørndal *et al.*, 2018). Thus, one kg of feed will produce about 1 kg of sludge with a dry matter content of 15 %. In practice, sludge and dry matter outputs can vary considerably between different farms and solid waste management concepts, as they heavily depend on feed conversion, feed spill and the recovery efficiency of the system (Nijhof, 1994; Cripps and Bergheim, 2000). According to Schneider *et al.* (2005), about 65 % of dry matter can be recovered in drum filtration. In this report, we will refer only to the production of solid waste based on feed input to illustrate the trends in the industry.

¹ Norwegian Directorate of Fisheries, retrieved 24.06.2019

3 Results

3.1 Number of companies and licences in Norway

In 2018, a total of 133 companies and 184 licences for smolt production were registered in Norway, of which 24 % of the companies and 27 % of the licences were filed in Hordaland (Figure 1). However, Hordaland only produced only 13 % of the country’s smolts. Although Nordland accounts for only 13 % of companies and 16 % licences, 30 % of all smolts were produced there.

Between 2000 and 2018, the number of companies and licenses been reduced by roughly 50 %. However, the number of companies and licences has remained relative stable in the last 10 years and declined by only 15-20 %. Considering the growing demand for smolt, this development indicates that the industry is consolidating, and that production capacities will become more centralized in the future (Figure 2).

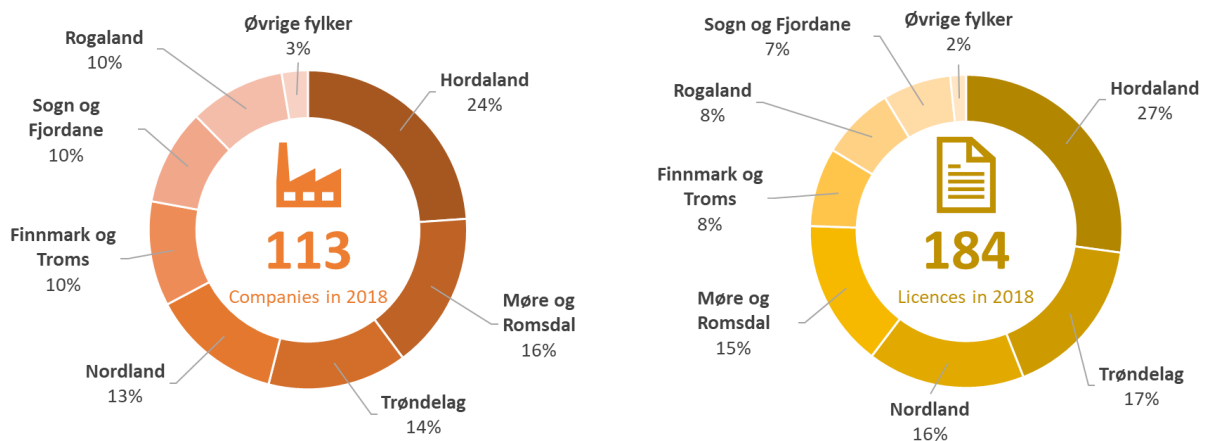


Figure 1 Geographic distribution of companies and licences to produce smolts in 2018.

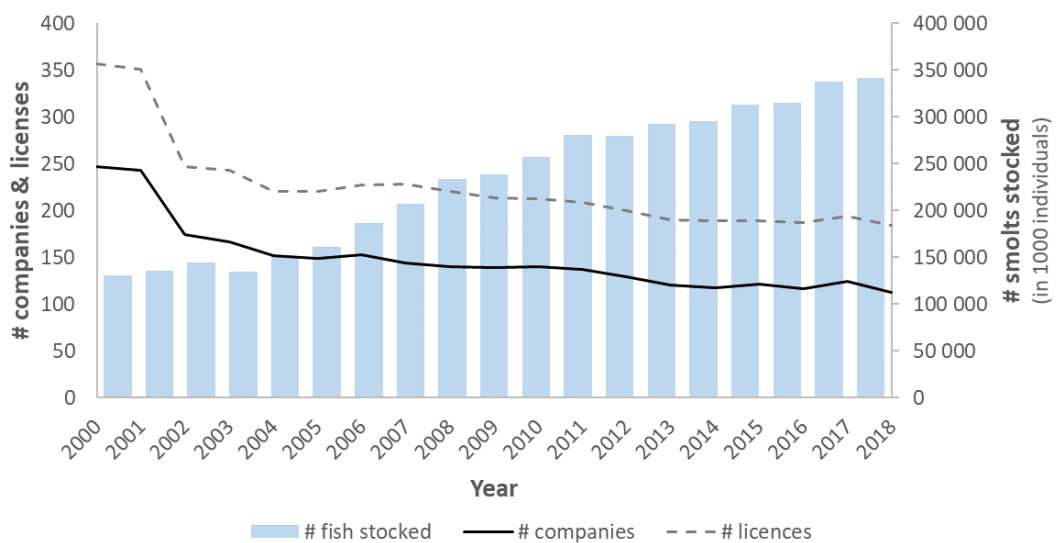


Figure 2 Historical development of number of companies and licences in Norway in relation to the total number of smolt stocked in grow-out operations.

3.2 Smolt production in Norway

The number of smolts refers to the reported number of individuals in each hatchery by the end of the of the respective year as livestock. This represents the number of smolts stocked in grow-out operations with an average accuracy of 99 % over the last 10 years². Thus, the reported numbers for standing stock at the end of the year reflect the yearly production numbers for smolts and the general trends of smolt production in Norway.

The yearly production of smolts in Norway tripled since 2000, to about 344 million individuals in 2018 (Figure 3). Currently, Nordland is the biggest smolt producer in Norway, responsible for almost 30 % of the countries smolt production in 2018 (Figure 4). Nordland and Trøndelag account for half of the total production. Including Møre og Romsdal, Finnmark og Troms and Hordaland, these five counties currently produce 92 % of all smolts in Norway.

Based on the growth trend in smolt production over the last 10 years, we can project a yearly production of at least 500 million smolts in Norway by 2030. An overview on the projected volumes and approximate geographic distribution can be found in Table 1.

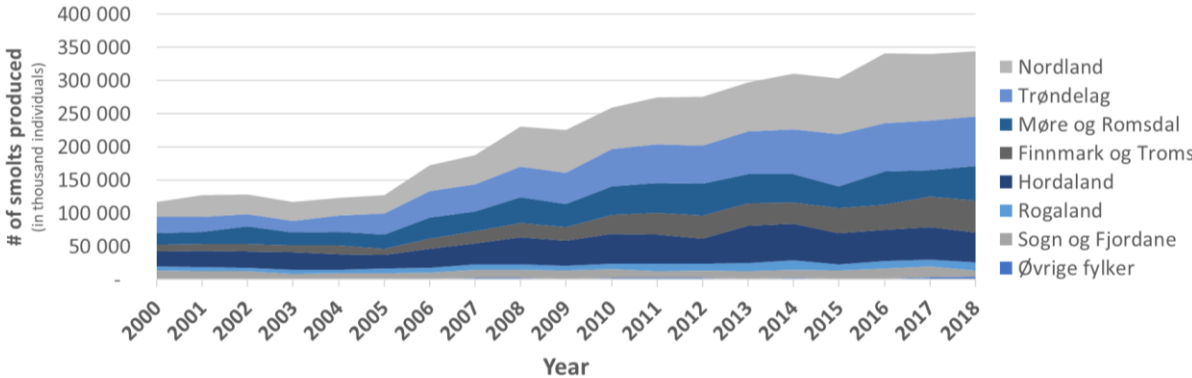


Figure 3 Historical development of smolt production in Norway.

² See Figure 2 for smolts stocked in grow-out.

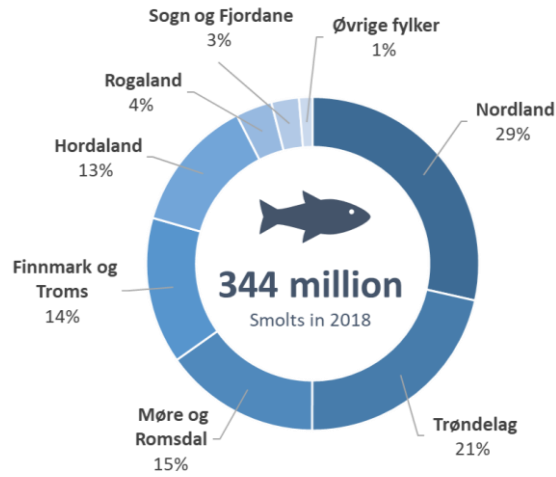


Figure 4 Geographic distribution of smolt production in Norway in 2018.

Table 1 Projected smolt production volumes and geographic distribution for 2030.

County	% ¹	# smolt (in thousand)
Nordland	29	143 399
Trøndelag	22	108 082
Møre og Romsdal	15	76 127
Finnmark og Troms	14	71 476
Hordaland	13	65 452
Rogaland	4	17 745
Sogn og Fjordane	3	13 455
Øvrige fylker	1	6 652
Total	100	502 388

¹ based on the geographic distribution in 2018

3.3 Estimating solid waste production and sludge volumes

3.3.1 Estimating solid waste production

As discussed in 3.2, the demand for smolt and the subsequent production is rising. Besides the increasing number of individuals, there is also a trend to grow bigger smolt to decrease the time at sea. A Nofima report from 2018 shows how average smolt sizes have increased over the last years, from around 80 g in 2000 to over 130 g in 2018 (Figure 5)(Iversen *et al.*, 2018). Sea lice, harmful algae blooms or diseases pose a serious risk to production and it is in the interest of salmon producers to reduce risks and thus optimize production costs in the long run. Several large producers have adopted this practice and it is expected that this trend will continue (Undercurrent News, 2018).

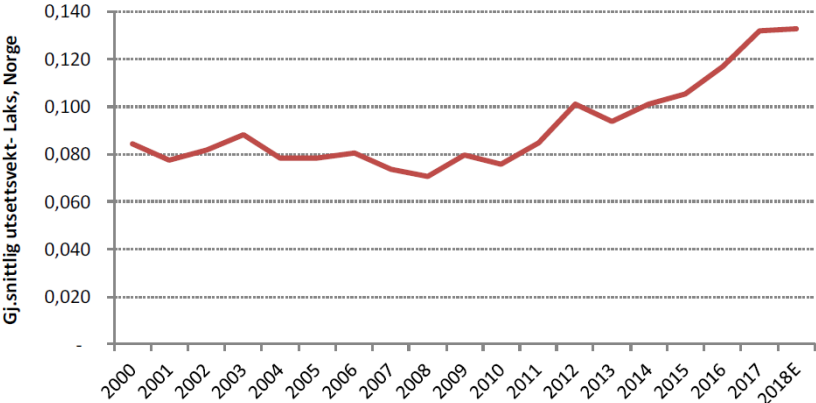


Figure 5 Average smolt weights at stocking (Iversen et al., 2018).

The data of Fiskeridirektoratet on the economics of smolt production reflects this trend, indicating that smolt size increased by more than 50 % over the last 10 years. Feed inputs in smolt production and average final weights of smolts were estimated by looking at the yearly cost of one kg of feed and the averages feed cost to produce one smolt. Economical feed conversion ratios have been steady over the whole production cycle and even slightly decreasing, indicating that the extra feed translates into an increased biomass per individual (Figure 6).

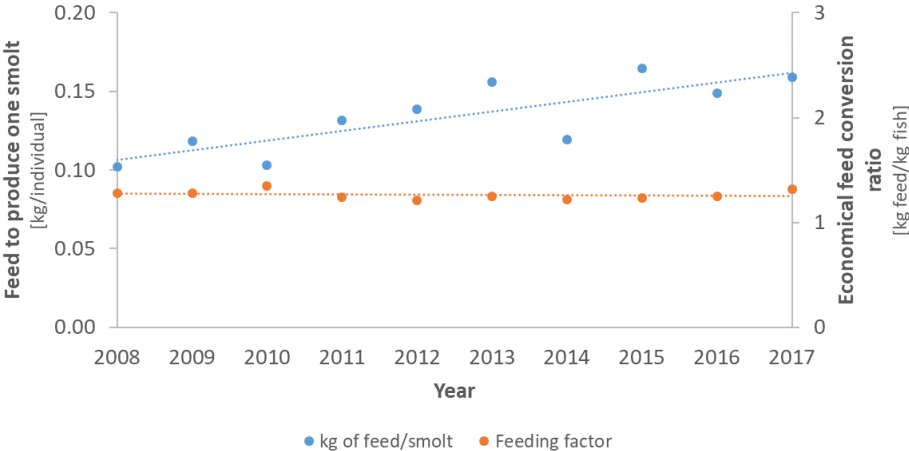


Figure 6 Calculated average amounts of feed used to produce one salmon smolt, based on data from Fiskeridirektoratet.

Using the previously determined feed requirements to produce one smolt, we can estimate solid waste production with a simple mass balance approach (see Section 2). Based on the total number of smolts and estimated feed loads, an estimated total of approximately 8 000 tons of solids have been produced as dry matter in Norway in 2017 (Figure 7). This corresponds to about 54 000 T of pre-thickened sludge with a dry matter content of 15 %.

These estimates show only the potential production of solid waste and does not take factors as feed spill or recovery efficiency into account, as these factors can vary significantly between different production systems (Nijhof, 1994; Cripps and Bergheim, 2000). However, the presented data shows a clear trend that the demand for more and bigger smolts will lead to a substantial increase in solid waste production. The yearly production of sludge has more than doubled over the last 10 years and will continue to increase rapidly in the wake of the expansion strategy to meet the production goals set for 2050.

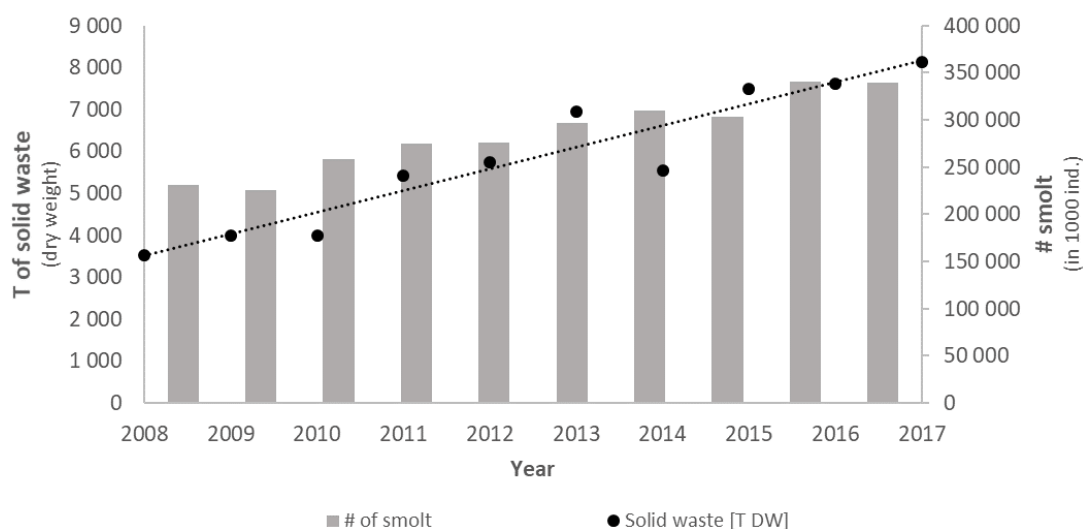


Figure 7 Estimated overall solid waste production in Norway as T of dry matter.

3.3.2 Examples for waste production in Norwegian smolt farms

Information on licenses and permits for commercial smolt production were retrieved from the Akvakulturregisteret of the Norwegian Directorate of Fisheries. As most farms try to operate at maximum capacity, the maximum permitted number of individuals should match the total yearly production of a smolts. After selecting only commercial salmon smolt producers and permits with active production, we analysed the 139 remaining production licenses for the maximum production capacity per farm.

We investigated two distinct cases: Firstly, we determined the median production capacity of all 139 production licenses and secondly, the average of the 10 biggest farms where solid waste valorisation might be especially interesting (Table 2). Using the previously calculated average value of 160 g feed to produce one smolt, we can estimate the total feed input and waste production per year.

Table 2 Distribution of production permits per farm in the investigated dataset (n=139). The median separates the upper half of the data from the lower part of the data and more suitable to illustrate the capacity of an “average” smolt farm.

	Production permit (in thousand individuals)
Lower quartile (Q1)	500
Median (Q2)	1 750
Upper quartile (Q3)	2 500
Average of 10 biggest smolt farms	14 250

Using the median from our dataset, an average smolt farm stocks 1.75 million smolts and produces 42 T of dry matter per year. In terms of volume, this translates into around 280 T of thickened sludge with a dry matter content of 15 % (Table 3). If the sludge is dried with advanced sludge treatment technology, this amount can be reduced to around 47 T of sludge with a dry matter content of 90 % (Bjørndal *et al.*, 2018).

From a sludge valorisation point of view, it is more interesting to know how much sludge is produced in large smolt farms. Taking the average of the 10 largest smolt farms from our dataset as an example, a large farm stocks over 14.2 million smolts and produces eight times as much solid waste as the average farm (Table 3). This corresponds to 342 T of dry matter, 2 280 T of thickened sludge (15 % DM) or 380 T of dried sludge (90 % DM).

Table 3 Examples for potential waste production in an average smolt farm vs. a large smolt farm.

	Case 1 <i>Average smolt farm</i>	Case 2 <i>Large smolt farm</i>
Number of smolts (in thousands)	1 750	14 250
Feed input (T/y)	280	2 280
Solids production as dry matter (T/y)	42	342
Sludge, 15% dry matter (T/y)	280	2 280
Dried sludge, 90% dry matter (T/y)	47	380

3.4 Waste treatment in Norwegian smolt farms

No uniform waste treatment concept is established in Norwegian smolt farms at this time. Currently, smolt facilities are being considered as land-based industry according to the Pollution Control Act (Forurensningsloven §7 & 11). However, the discharge limits are issued and controlled on county-level. As opposed to licences issued before 2010-2015, new discharge permits are increasingly based on emissions and the carrying capacity of the recipient, rather than on fish biomass or feed input (Bergheim, 2019). If the discharge has been evaluated as safe for the recipient, effluent treatment might not be required at all. Thus, the need for solid waste collection and the subsequent potential for valorisation will differ between locations and depend on the requirements of the local environmental department at Fylkesmannen. However, any new farming licences will have to comply with the new emission-based limits and all land-based facilities should have a new licence by 2021 (Pettersen, 2018). Therefore, it is expected that more farms will need to implement measures to treat their effluents.

Since the removal and processing of solid waste usually requires significant investments, the extent to which effluents are treated is usually an economical trade-off rather than an environmental one (Cripps and Bergheim, 2000). The main challenge in water treatment of fish farms is a highly dilute waste stream, with only a few milligrams of suspended solids in large flows.

As farms have been scaling up, drum filters have become the main tool to remove solids due to their capability of handling large flows with a low footprint (Cripps and Bergheim, 2000). Drum filters can concentrate these solids to approximately 1 %-2 % of dry matter content and create a manageable secondary waste stream that can be treated further (Table 4).

Simple settling basins or more advanced off-line settling units can be used to concentrate solids up to about 5-10 % (Timmons and Ebeling, 2007). The solids content can be increased to 20-30 % by using a belt filter press or centrifugation. Further concentration of the sludge is only possible with drying, which can deliver solids with dry matter contents of 90 % or more. However, the amounts of collected solids/sludge will be lower in practice and heavily depends on the efficiency of the solids collection process. According to Schneider et al. (2005), about 65 % of dry matter can be recovered in drum filtration.

Table 4 Examples for dry matter content and volumes for different solid waste treatment processes, assuming that one kg of feed will produce 150 g of solid waste (Timmons and Ebeling, 2007).

Waste stream	DM content	Volume per kg of feed
Drum filter effluent	1 %	15 m ³
Settled sludge	5-10 %	1.5-3 m ³
Dewatering (e.g. belt filter press)	20-30 %	0.5-0.75 m ³
Dried sludge	90 %	0.17 m ³

The increasing use of recirculating aquaculture system (RAS) technology in smolt production might facilitate the collection of sludge in the future (Folkestad, 2018; Hatchery International, 2018). In RAS, the first step in water treatment is the removal of solid waste before the water can be reused (Timmons and Ebeling, 2007). Therefore, most smolt farms using RAS technology should have a readily accessible solid waste stream. If the solid waste stream cannot be discharged directly, further thickening/dewatering is usually implemented on site to reduce sludge volumes for storage.

So far, there is no central register that shows whether a farm uses RAS technology or what kind of waste treatment strategy is implemented. In 2006, only between 1 % and 2 % of the total hatchery sites were using RAS technology (del Campo *et al.*, 2010). Since then, the government has simplified the rules and regulations to obtain permits for land-based production and increase the competitiveness of land-based farming (Regjeringen.no, 2016). In 2018, Nofima estimated that about 20% of the hatcheries were based on RAS technology (Iversen *et al.*, 2018), indicating that the potential to collect solid waste is increasing.

According to Klemet Steen from Lerøy AS, almost 70 % of the smolts stocked in their grow-out operations were raised in RAS (pers. comm.). Currently, sludge collected in their systems is being used to create biogas and agreements are in place to also supply dried sludge for the industrial production of agricultural fertilizer. Similar developments can be observed in other parts of the country as well, where solid waste from fish farms is being recognized as a valuable resource (Saue, 2018; Sterner AS, 2018; SalmonBusiness, 2019).

Besides using RAS technology for large-scale smolt production, the planning and development of RAS farms with a total capacity of about 1000-2000 T for the land-based grow-out of salmon is ongoing (Terjesen, 2016). If all current, and arguably very ambitious plans in developing land-based salmon farming projects would succeed, over 10 % of Norway's salmon could be produced on land (Furuset, 2018). These large farms could become a new, valuable source for the collection and valorisation of sludge.

Recently, constructions have been completed at the first commercial Norwegian land-based production facility for salmon at the Fredrikstad Innovation Park in Østfold county. In May 2019, the first 100 000 smolts have been stocked and permits for further expansion are in place. At full capacity, this farm will produce 6 000 tons of salmon on land annually. Assuming that approximately 1 kg of feed is required to produce 1 kg of salmon in RAS, this translates to an annual production of 900 T of solids as dry matter. Thus, this single site in Østfold would produce 2.5 times as much solid waste as our example for a large smolt farm (see Section 3.3.2).

4 Conclusions and outlook

We have observed two main trends that are relevant for the development of the Norwegian smolt industry. Firstly, the industry shows strong signs of consolidation and centralization, as the number of companies and licences is decreasing while smolt production is increasing.

Secondly, we have observed that average smolt sizes have been increasing over the last years and this trend is likely to continue. More smolts with higher individual weights will drive feeding requirements and the subsequent production of solid waste in land-based smolt farms in Norway.

It is not clear how much of this resource is readily available for collection or commercial exploitation at the moment. The practical exploitation of this resource depends on whether solids are being collected and to which degree they can be dewatered to make transport feasible. In terms of available technology, the challenge to separate and concentrate solid waste is solved and a wide variety of commercial solutions are available for effluent treatment.

The main challenge in waste collection is a question of economics, since waste treatment usually incurs significant capital and operational expenses. In most cases, strong legal or economic incentives are needed to ensure that measures for effluent treatment are implemented. As new environmental regulations are being implemented, we expect that the need for waste treatment will increase in Norway in the future. With the increasing use of RAS technology in smolt production and grow-out, the collection of solid waste will become easier due to a readily available waste stream.

Large-scale RAS facilities such as the land-based production system in Fredrikstad are of special interest due to the scale of production and the system-inherent need to separate solids during operation. Thus, RAS systems for the production of smolt or even the grow-out of salmon are prime candidates for a feasible valorisation of solid waste from fish farms.

Looking at the historical trends and the ambitious goal of reaching a yearly production of 5 million tonnes of seafood in 2050, the management of solid waste will become instrumental to ensure a sustainable expansion of the industry in compliance with the UN Sustainable Development Goals. Considering that waste volumes will increase while the industry consolidates, it will become more likely that centralized solid waste valorisation processes will be not only feasible but also profitable through economy of scale.

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