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Lead beneficiary: Multivector AS
Authors: Hallstein Baarset (Multivector AS), Johan Johansen (Salten Havbrukspark AS)
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GLOSSARY OF ACRONYMS

Acronym	Definition
DM	Dry Matter (percentage of dry matter in material)
GAIN	Green Aquaculture Intensification
HSE	Health, Safety and Environment
RAS	Recycling Aquaculture System(s)
RH	Relative Humidity
WCPB	Waste collection and processing building

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1. Introduction

Mortalities and discarded fish are substantial side streams from the aquaculture industry in terms of both volumes, costs of operation, HSE hazards and potential value. Multivector has investigated a potential solution for a more sustainable, less hazardous and more cost-efficient method for mortality disposal.

The aquaculture industry in Norway is currently undergoing an intensification process, where production at each location is significantly increasing. According to Bjørndal & Tusvik (2017), smolt production in Norway has experienced an increasing intensification in the period 1994 – 2015. The number of companies and permissions have been reduced in the range of 50 %, while the amount of smolt produced in the same period has been increased more than 3-fold. A similar development is seen for salt water fish farms.

Task 2.1 in the GAIN project aims at valorization of aquaculture side streams. There are two main side streams identified from fish farming: 1) sludge containing faeces and remains of fish feed; 2) mortalities and discarded fish. Mortalities is an inevitable side stream from all varieties of fish farming – sea cages, RAS and flow-through systems, as well as in transport vessels for live fish.

In order to eco-intensify the Norwegian aquaculture industry, mortalities and discarded fish need to be processed and converted into new resources. According to Ernst & Young (2017), the mortality rate in sea cages in Norway is about 19%. This represents 53 million fish, with a corresponding annual cost of disposal of about 1 billion NOK (≈ € 100 M). Similar estimates are given (Nofima/SINTEF Ocean/***BarentsWatch*** webpage): Salmon mortality rate in 2018 was about 16.4 %, equalling 55.3 million fish. According to Nofima/SINTEF Ocean/BarentsWatch webpage, 15 - 20 % of the number of salmon and trout in sea cages are lost. This number includes escapes and is consistent with Bjørndal & Tusvik (2017). In terms of weight, losses correspond to 6 – 9 % of the biomass.

Further, adding to this figure, according to Fiskeridirektoratet (2018) the reported loss in landbased smolt production in Norway in 2017 is presented in Table 1 below.

Table 1: Loss in Norwegian smolt production 2017.

Fish species	Number of fish (x1000) mortality	Number of fish (x1000) discarded
Salmon	54 162	49 074
Trout	5 147	3 754

According to Bjørndal & Tusvik (2017), mortality in the first feeding month is typically 4 %, then subsequently 0.5 % per month, increasing to a monthly mortality rate of 0.75 % in sea cages.

As Table 1 shows, the order of magnitude of mortalities and discarded fish is the same. In many smolt farms in Norway smolt is screened prior to vaccination, in order to discard fish with deformities and inadequate growth performance. Average size for mortalities in smolt farms represents less value and biomass that mortalities at sea cages. However, side streams from both smolt farms and sea cages need to be processed to obtain eco-intensification of the aquaculture industry.

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EC Regulation No 1774/2002 of the European Parliament and of the Council of 3 October 2002 define health rules concerning animal by-products not intended for human consumption. Similar regulation is adapted by the Norwegian government (Lovdata 2016-09-14-1064). Mortalities and fish with signs of illness are classified as "category 2 animal by-products" (mortalities), while living fish with no signs of illness are classified as "category 3 animal by-products" (discarded fish). According to EC Regulation No 1774/2002 dried product from "category 3" may be utilized in a multitude of applications including animal feed, while "category 2" use is restricted to:

a. Bio energy production
b. Technical applications
c. Fertilizer
d. Feed for fur animal breeding
e. Feed for zoo and circus animals
f. Other non-food producing animals

1.1 Objectives

The eco-intensification of the aquaculture industry requires a cost-efficient and safe handling of mortalities and discarded fish in compliance with current regulations. In GAIN Task 2.1, an innovative technology for mortality disposal is being tested. After investigating different drying technologies, superheated steam as drying media in a dryer with mechanical fluidization (Nygaard & Hostmark 2008) was identified as the potentially most cost-effective one. This technology eliminates the need for chemicals, eliminates hazards in the working environment for personnel, are reduces the operating costs, compared with current practices, which are described in section 2.

2. State-of-the-art of mortalities and discarded fish disposal

Current practice in Norway for mortalities and discarded fish disposal in aquaculture is ensilage. According to Møretrø & al (2010), mortalities should be grinded, in order to obtain particle of 10 mm maximum size and mixed with formic acid until pH lower than 4 are reached: the mixture should be stored for at least 24 hours for stabilizing the ensilage. In most fish farms, mortalities and discarded fish are mixed and treated in the same process, which includes:

1. Grinding;
2. Mixing with formic acid;
3. Storage in containers;
4. Transport, according to these alternatives:
    a. Containers transported by truck
    b. Ensilage pumped to ship
5. Delivery to processing plant being:
    a. Products for technical applications

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b. Biogas plant

The process outlined above involves both challenges regarding HSE hazards and operating costs.

2.1 HSE hazards

Occasionally, there have been accidents where workers have been exposed to formic acid during the ensiling process. This has led to injuries, ranging from irritation to the skin to some case of fatal injury. The inbound transport of formic acid to fish farms and outbound transport of ensilage for disposal involve environmental hazards. Road transport of the ensiled products, especially in winter time on poor standard roads in rural areas in Norway pose such a hazard, as leakage from tank trucks caused by a road accident, poses a potential danger to local environment. Handling of ensilage containers in rough sea is another hazard.
Mortalities pose a biological hazard with risk of contaminating other fish at the same site and even in other fish farms by transport of contaminants from place of origin. Securing the ensilage as a stable product demands a residence time of 24 hours Møretrø & al (2010): shortening this time would reduce the biological hazard.

2.2 Operating costs

There is a variation in the operating cost of mortalities from site to site depending on actual logistic costs. Operating costs of ensiling mortalities were estimated based upon market prices available on the internet and by interview with personnel at smolt plants:

Cost of formic acid: ≈€ 300 per 0.2 m^3 container
(additional transport cost will vary from site to site depending on actual logistic cost)
Cost of collection and disposal: ≈€ 0.2 per kg of ensilage
(variation from site to site depending on actual logistic cost)
Labour cost of handling: ≈€ 30 per day
Equipment for personal protection: ≈€ 360 per year

Table 2 shows an example of annual operating cost for ensilage of 20 000 kg of mortalities. This is a typical number for a large smolt farm or a small sea cage location. Some fish farms add water to the grinded mortalities, increasing costs of both formic acid and ensilage disposal.

Table 2: Example of annual operating costs by ensilage of 20 000 kg of mortalities

Type	**Amount**	**Cost**
Formic acid	600 l + transport € 150	€ 1 050
Ensilage disposal	€0.2 per kg x 20 600 kg	€ 4 120
Labour cost	€360 per day	€ 10 950
Protective equipment	€360 per year	€ 360
Annual cost		**€ 16 480**

Alternatives that reduce operating costs for handling of mortalities will facilitate eco-intensification of the aquaculture industry.

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3. Methodology

For compliance with Regulation (EC) No 1774/2002 mortalities need heat treatment. Heat treatment at site before transport seems to best way to deal with the challenges of the combination of eliminating HSE hazard and operating cost efficiency. Drying of mortalities has not been common practice in Norway, but it is used for disposing food waste, including fish residues, by hotel and restaurants. Based upon Nygaard & Hostmark (2008), using superheated steam as drying media in a dryer with mechanical fluidization ensures sanitation of fish meal at drying times as short as approximately 1 minute. Results in their study indicate that pathogens will be efficiently inactivated by short time exposure to superheated steam.

Considering the similarity of fish meal produced from salmon residue and smolt mortalities, led to the selection of this technology as the best suited one for sanitizing of mortalities and discarded fish. Further, protein quality in dried fish meal is well preserved by using mechanical fluidization and superheated steam according to Nygaard & Hostmark (2008). Assumedly, the protein quality of dried mortalities will be better than the ensiled product. Validation of dried mortalities being a stable product without microbial activity should allow for a potentially higher value of the dried product. Drying of mortalities at site of origin, eliminates transport of substantial amounts of water, as the ensilage today typically contains 80 – 85 % water. Transport of the dried product in bags compared to tank transport cuts transport costs with typically another 50 %.

The cost-effectiveness of mechanical fluidization and superheated steam as a process for disposing mortalities and discard from the aquaculture industry will be tested in GAIN through the following steps.

1. Validation of the applicability of the technology for on-site drying of mortalities;
2. Production of dried product samples for analysis of microbial inactivation;
3. Calculation of operating cost;
4. Establishment of a hardware and software setup with key operational parameters for installation of a demonstration facility.

Figure 1 BioWaste 20 Dryer from Waister

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First tests are already on going, using a BioWaste 20 dryer machine from Waister (formerly Multivector), see figure 1, which is being used for drying of mortalities and discarded fish at the waste collection and processing building (WCPB) adjacent to Sundsfjord Smolt (Figure 2). The machine was installed by Waister with temporary connections to electricity, inlet cooling water, outlet cooling water and condensate discharge. Installation of the BioWaste 20 dryer, parameter setup and initial tests were conducted by Waister. Mortalities were delivered by Sundsfjord Smolt to the WCPB from their regular smolt production. Test drying was performed in collaboration with Salten Havbrukspark, who took part in the long-term follow-up on the site supported by Waister.

Figure 2 Waste collection and processing building (WCPB) adjacent to Sundsfjord Smolt

Mortalities arriving in buckets were added to the inlet buffer of the BioWaste 20 dryer. The drying chamber was fed by a screw in the bottom of the inlet buffer with a cutting mechanism in the end of the screw.

The drying process is semi-continuously, meaning that there is a continuous sequence of feed and stop periods. Each feed allows a small amount of mortalities into the drying chamber. Duration of each feed period and stop period depends on the RH level inside the drying chamber, which is controlled by the machine control system. Rotors equipped with paddles of a specific patent protected design, secures very good mechanical fluidization of the product inside the drying chamber. The paddle design secures homogenous distribution of all particles independent of particle size and weight inside the drying chamber, allowing a maximum surface available for efficient evaporation of water. Superheated steam as drying agent secures a more energy efficient evaporation compared with air used in a multitude of dryers.

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After a certain number of feeds the BioWaste 20 machine goes into a final drying stage, bringing the product inside the drying chamber to a DM level above 90 % as well as securing a necessary minimum residence time of the last mortalities being fed into the drying chamber. The final drying stage lasts in the range of 10 – 20 minutes and is completed by a discharge of an amount of dried material into a bag. Sufficient amount of dried product remains inside the drying chamber, when the machine returns to the semi-continuous drying, thus securing fluidization inside the drying chamber. Figure 2 shows a schematic presentation of the BioWaste 20 dryer.

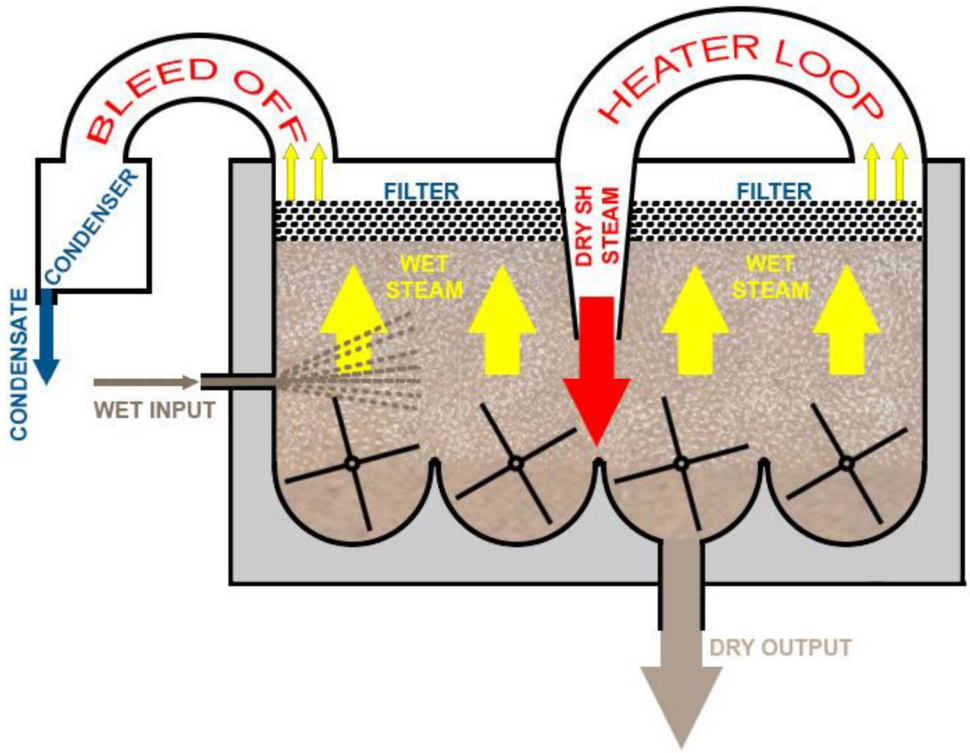

Figure 3 Schematic presentation of dryer based upon mechanical fluidization and superheated steam

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4. Results

During the first year of GAIN, the BioWaste 20 dryer machine was installed in the WCPB in Sundsfjord, in order to perform preliminary test, as described in the previous section. These tests highlighted the need of adjusting the operational parameters, compared with the setting used in treating mixed food waste.

Mechanical fluidization is essential for an efficient drying process in the BioWaste 20 machine. Obtaining mechanical fluidization has proved to be challenging, due to stickiness and content of fat in the grinded mortalities. Changing parameter settings for feeding time, waiting time, allowed RH level and number of feeds before final drying, was necessary to avoid adhesion of material to rotors, paddles and surfaces inside dryer, obtaining fluidization while initiating the drying process at start-up and when initiating a new drying sequence.

The finalized dryer parameter setup will be implemented in the planned permanent installation of a Multivector 15 machine for operation during the second year of the project.

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5. Conclusions

Mortalities and discarded fish are substantial side streams from the aquaculture industry in terms of both volumes, costs of operation, HSE hazards and potential value. Activities carried out thus far in GAIN Task 2.3 by Multivector led to identify drying of mortalities as a promising alternative to current practices, i.e. ensiling: this innovative method would not require the addition of chemicals (i.e. formic acid), would eliminate HSE hazards and is likely to reduce disposal cost. Initial tests have demonstrated that this process is feasible: in order to achieve the goals of Task 2.1 the following activities are foreseen.

1) Establishment a demonstration facility

The BioWaste 20 dryer will be substituted by an upgraded Multivector 15, equipped with remote access via the Internet, permanent connections to electric power, inlet water, outlet water and condensate discharge. This allows for remote monitoring and documentation of process performance and power consumption. The Multivector 15 dryer machine will be installed in WCPB in 2019, and thereafter be available for demonstration and dissemination. The machine will be operational, process mortalities and discarded fish from Sundsfjord Smolt during this period. Parameters in the permanent Multivector 15 dryer machine are set for reliable continuous operation without supervision, allowing operators from the fish farm to insert mortalies and operating the dryer.

2) Compliance with Regulation (EC) No 1774/2002

In order to demonstrate that the drying method is compliant with the legislation, dried product samples from mortalities ("category 2") will be analysed for the presence of:

- Clostridium perfringens
- Salmonella
- Enterobacteriaceae

Results from these measurements will make up a basis for compliance documentation of the viability for this method in terms of microbial inactivation. Primarily, focus will be on application of dried mortalities with the highest value in accordance with current government regulations. Secondarily, potential applications that prerequisite changes in government regulations will be pointed out.

3) Economic analysis

In the third year of GAIN, operational costs of the innovative method for mortality disposal will be compared with those of current practices. Further potential income generated from upcycling of the product will be considered, provided that the innovative method demonstrates a non-hazardous product, this allows for alternative application of the "category 2" side stream.

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