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Uneaten Feed Quantification in Fish Farming Growing Phase of *Dicentrarchus labrax*, Feeding Flow and Distribution Modes Effects

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ABSTRACT

The economic and environmental sustainability of fish farms depends on the improvement of farming practices. Considering the fish feed high cost and environmental impacts, fish farmers continually need to improve feed efficiency, essentially through good feeding practices. Reduction of uneaten feed is an unavoidable objective for fish farmers to achieve this goal. This study aimed to improve the feeding practices and highlight the effects of slowing feed distribution flow rate on uneaten feed rate (Ruf) in caged sea bass (*Dicentrarchus labrax*) under continuous and discontinuous feed distribution modes in the commercial aquaculture farming conditions of M'diq Bay, Moroccan Mediterranean. A conical polyamide net was placed in the external, surrounding position of the entire experimental cage to ensure capturing all uneaten feed. Collected wet feed pellets were dried and weighed to quantify uneaten feed; three repetitions were performed during each experiment for each feed distribution mode and flow rate. Results showed that uneaten feed quantity (Q_{df}) was higher in manual discontinuous distribution mode at a fast flow rate of 20 kg/min. Slowing down the fish feeding flow rate from 20 to 10 kg/min reduced the uneaten feed rate from 3.7 to 0.2%. Similar findings were observed for continuous pneumatic fish feed distribution mode where rate decreased from 0.8 to 0.02%. Significant statistical differences between the two fish feed distribution modes and between the two experienced fish feeding flow rates were observed. The further high positive impact of slow and continuous fish feeding flow was recorded on feed efficiency in sea bass farming.

INTRODUCTION

Aquaculture remains one of the fastest growing food producing sectors worldwide. Its contribution to total seafood utilized for human consumption reached 49.2% in 2020, on a par with capture fisheries, compared to only 13.4% in 1990 **(FAO, 2022)**. Fed aquaculture production has continued to increase from less than 60% prior to 2000 to 72.2% in 2020 to total farmed aquatic animal **(FAO, 2022)**. This evolution responds mainly to an increasing consumer demand for fish products in parallel with a decrease in fishing catches.

Therefore, number and size of aquaculture farms are increasing worldwide. Most countries including Morocco are setting up and/or updating their aquaculture strategies to develop national seafood productions, with a focus on investors by public authorities. COVID 19 pandemic crisis has further highlighted the importance of primary productions, refocusing interest on essential matters IN public policies rather than household.

International fish products market remains a highly competitive market; sales prices are reduced to the minimum, while fish farming main inputs costs are tending to increase. Covid 19 pandemic crisis and ongoing conflicts have further exacerbated this development by exponentially increasing the cost of feed and logistics **(Gosh *et al.*, 2022)**. All these factors increasingly reduce farms profit margins, forcing fish farmers to award a permanent search to implement best farming practices and techniques to improve productivity.

Fish feed cost represents more than 50% of any fish farm expenses **(Sveier & Lied, 1998; Rana *et al.*, 2009)**. Its optimization becomes crucial and primordially important to ensure fish farms economic competitiveness **(Wang *et al.*, 2007)** and reduce environmental impacts, such as eutrophication and acidification surrounding aquatic environment **(Besson *et al.*, 2019; Wilfart *et al.*, 2019)**.

Feed efficiency is related to several management factors, such a feed physical form and quality, feed distribution timing and duration, feeding frequency in addition to methods **(Ang & Petrell, 1998)**. These factors and others may reduce uneaten feed quantities and minimize costs and environmental impacts.

The present study focusses on the effects of caged sea bass (*Dicentrarctus labrax*) feeding practices under commercial conditions on feed losses. The purpose is to define the optimal feeding flow rate and the most appropriate feed distribution mode generating the least negative impacts.

MATERIALS AND METHODS

1. Study site

This study was carried out at the Aquamdiq fish farm in M'diq bay in the western part of the Moroccan Mediterranean coast. Farm’s site is 2.3km east of M'diq beach (35°41'16.3 "N, 5°19'23.1 "W) (Fig. 1).

Fish farm culture facilities are composed of 21 high density polyethylene (HDPE) circular floating cages (7 cages and 14 cages, with 7 and 12m in diameter, respectively). Smaller cages were dedicated for fingerlings pre-growing from 3 to 50g and larger cages for fish growing until reaching commercial sizes (about 350g). Annual production capacity of this farm is about 220 tons, with an average production cycle of 20 months.

Farming cages are set on a bathymetric range of 18 and 22m, covering a surface area of 5.2ha.

Seawater temperature in summer ranges between 19.9 and 21.2°C for surface water and little cooler in depth, while in winter, it fluctuates between 14.8 & 15.8°C on surface and deeper, respectively. Salinity in sea surface is homogeneous and varying between 35.9 and 37‰. The bay's water are relatively well oxygenated both at surface and deeper; regardless of season, it varies from 6.2 to 10.7mg/ L in summer and from 5.8 - 9.6mg/ L in winter **(Lakhdar *et al.,* 2001)**.

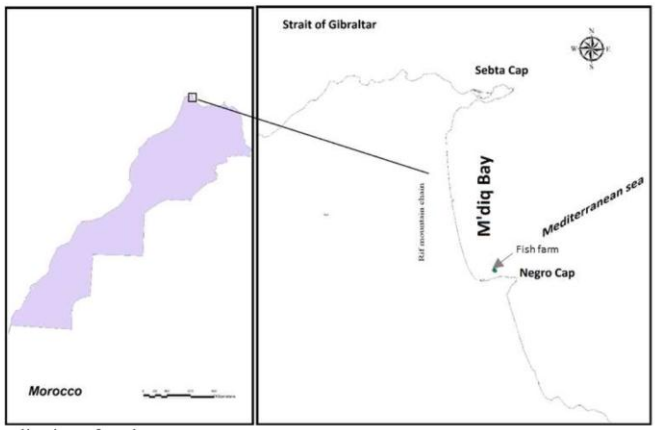

Fig. 1 : Location of the study area

2. Feed delivery modes and flow rates

The experiments were carried out under commercial operating conditions in a 12m-diameter floating cage, equipped with an 18mm- mesh size rearing net made of polyamide. The latter has 9m in immerged depth and 1017m^3 in a rearing volume. Initial stocked fish number in rearing cage was 86,657 sea bass (*Dicentrarchus labrax)* aged 631 days, with an average weight of 205g. Total initial biomass was 17,808kg, with a starting rearing density of 17.5kg/ m^3.

These experiments duration was 14 days. Average target daily weight gain of D_{wg} = 0.5 g per day was determined by previous samplings prior to starting the experiences. 100 live fish (n) were sampled from the experimental cage. Each fish individual was weighed to determine the initial mean weight (W_{asi}(g)) and initial sample biomass (B_{si}(g)). After d=15 rearing days, and before starting the experiments, another sample of 100 live fish (n) was taken and individually weighed to determine the final mean weight (W_{asf}(g)) and the final sample biomass (B_{sf}(g)). The daily weight gain (**D_{wg}**(g)) was thus determined using the following equation:

Equation (1): $$\mathbf{D_{wg} = (B_{sf} - B_{si})/d=((W_{asf}*n)- (W_{asi}*n))/d}$$

Physiological mortality was collected daily and deducted from the number of farmed fish number. Biomass and density estimates were counted for mortality, with minor daily change.

Feed used was extruded and sinking (Aller-aqua blue X brand) Ø 4.5mm, made from meal and oil of both fish and vegetable sources. Feed digestible energy was estimated at 17.6 MJ kg-1, 41% protein and 19% fat. Daily fish feed ration was calculated using below equation; it was distributed once daily at 10:00 am.

Equation (2): $$\mathbf{Q_f = B * R = (N * Wa) * R}$$

Where, B is the fish biomass (Kg); N is the number of fish; Wa is the average weight (Kg), and R is the feed ration rate (Kg of feed per 100Kg of fish per day), given as recommended feeding level by feed manufacturer and adjusted by the fish farmer in relation to fish appetite.

Two flow rates were thus tested in triplicate using two distribution modes, continuous (pneumatic) and discontinuous (manual) for the same feed ration.

A pneumatic cannon (Fig. 2) was used for the continuous distribution mode, with a maximum distribution capacity of 3,200kg of feed per hour, corresponding to a maximum flow rate of 53kg/ min, made by Elimat company. The cannon was equipped with a 1m^3 capacity HDPE tank, a diesel engine driven turbine, and a graduated valve that allowed air flow rate variation. Three repetitions were constituted for this mode with a fast flow rate F_{c1} = 20Kg/ min, corresponding to an opening of 4cm of the machine graduated valve and three others, with a slow flow rate of F_{c2} = 10kg/ min, corresponding to an opening of 2cm.

Manual feed distribution was executed with a 350g plastic feed shovel (Fig. 3) to evaluate the discontinuous mode. Three repetitions were performed for manual mode with a fast flow rate equivalent to the maximum possible speed manually, and then three others with a slow flow rate on doubling distribution time. Consecutive times for filling the manual shovel and changing feed bags were recorded by a chronometer and cumulated to deduce them from feeding time, allowing to determine effective feeding rate F_{d1} and F_{d2}.

Feed distribution frequency was performed once a day; experiments lasted for 12 working days, with one repetition per day. The first six days were specified for manual mode, followed by six others for pneumatic mode.

3. Uneaten feed quantification

A conical polyamide net was made by local menders designed to be placed in external surrounding position of the entire experimental cage to collect all uneaten feed. The conical net was 4mm in mesh size, 12m in top diameter and 14m in bottom diameter, with 11m in depth. To eliminate stress effects generated by net installation, a delayed period of 4 days was observed before the start of experiments. A quick cleaning of the installation was done beforehand. Few minutes after feed distribution, waste trapped between net bypass and net rearing was collected by two experienced divers.

Removed materials consistited of a mixture containing uneaten feed (Fig. 4), faeces and biofouling composed of mussels, algae, and barnacles (Fig. 5). Collected materials were hand sorted to keep only uneaten feed pellets.

Fig. 2. Pneumatic feeder cannon

Fig. 3. Manual feeding

Fig. 4. Mixture of uneaten feed with other waste

Fig. 5. Mussels, algae and barnacles

Collected wet feed pellets were then dried at 70°C for a duration determined following experiments of soaking and drying 3kg of ALLER BLUE X 4.5mm feed distributed on 3 small nets and dried using a dehydrator reference "SFD 4235WH" (Food Dehydrator SENCOR), equipped with electronic thermostat from 40 to 70ºC and timer. Dried uneaten feeds were weighed using a Baxtran precision balance. Time required to dry wet feed was 04 h±15 min to remove 40.3%±0.8% of collected wet feed weight. Water removed percentage is comparable to that of **Vassallo *et al.* (2006)**.

Uneaten feed rates were calculated according to the following equation (3):

$$\mathbf{R_{uf} = Q_{df} / Q_{f}.}$$

Where, R_{uf}: Uneaten feed rate (%); Q_{df}: Dry uneaten feed quantity (Kg); and Q_{f}.: Feed distributed quantity (Kg).

The data obtained from different trials, were analyzed using a one-factor ANOVA, with a threshold of $\alpha = 0.05$ by SPSS software (IBM SPSS statistics 20) to compare uneaten feed average amounts between flow rates and those between distribution modes.

4. Availability time of distributed feed inside cage

Availability time of distributed feed (Td) inside cages depends on many factors linked to feed characteristics (density, dimensions, sinking speed, etc...), site, physical and chemical parameters (temperature, salinity, current, etc.), net characteristics (net dimensions, mesh size, net fooling stage) and farming conditions (fish density, feed quality, feeding ration, fish appetite, feeding frequencies and distribution modes). All these factors influence the time covering the availability of the feed distributed inside the net cage before being drained outside by current **(Alver *et al.*, 2004)**.

Time distributed feed availability was surveyed and reported by divers recording time appearance of the first unconsumed pellets, sinking at the bottom of collecting net. This approach of time distributed feed availability assessment remains approximate since information on the exact time when pellet was first distributed inside the rearing net reaching the collecting net bottom was impossible to obtain under experimental conditions. It could be hypothesized that first uneaten pellets might be the first distributed.

Once the time distributed feed availability duration was defined, it was compared with the reactivity rate (feed intake velocity) of farmed fish during feeding period according to published results.

5. Water temperature and current measurement

The water temperature was recorded from 29/05/2022 to 13/07/2022 at a frequency of one hour and at a depth of 3m, using a datalogger thermometer (±0,3 °C precision).

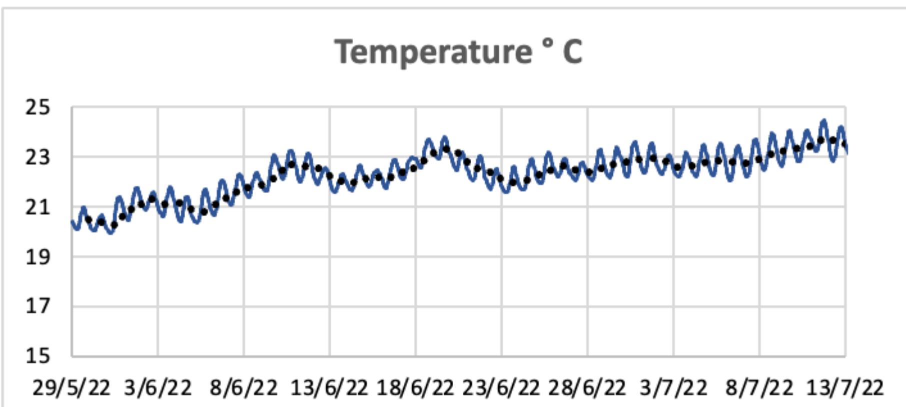

Fig. 6. Recorded temperature using datalogger thermometer (±0,3 °C precision)

Seawater current velocity was estimated at Aquam'diq farm' site using shyfem hydrodynamic model (System of Hydrodynamic Finite Element Modules). This model is recommended for coastal areas to evaluate the water circulation. This open-source application (**Umgiesser *et al.*, 2018**, https://github.com/SHYFEM- model/shyfem) was developed at CNR-ISMAR in Venice. The model allows for barotropic current velocity using input data of tide, bathymetry and atmospheric parameters such as wind, cloud cover, irradiation and pressure. An irregular grid mesh was developed and integrated with bathymetry (Fig. 7).

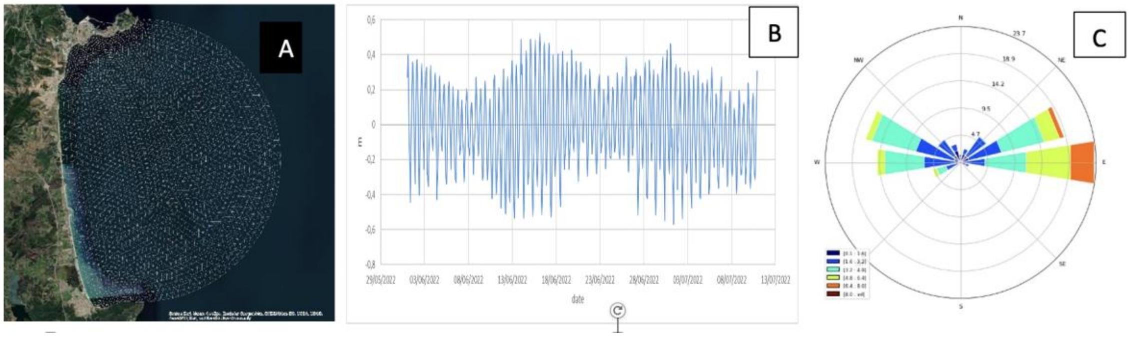

Fig. 7. Input parameters for simulating water dynamics in the Aquam'diq farm (A: Grid Mesh, B: tidal time series, C: M'diq wind rose

RESULTS

The experiments were carried out under comparable environmental conditions. Results are summarized in Table (1), supported with detailed differences in the amount of uneaten feed.

Table 1. Experiences results: Determination of Uneaten Feed rate related to different feed distribution flow and methods

Experience dates (2022)	**June 19, 20 and 21**	**June 22,23 and 24**	**June 27, 28 and 29**	**June 30, July 01 and 02**
Feed distribution method	**Discontinuous (Manual)**		**Continuous (pneumatic)**	
	F_{d1}	F_{d2}	F_{c1}	F_{c2}
[1] $\mathbf{Q_f}$: Quantity of feed distributed (Kg)	100	100	100	100
F: Effective feed distribution flow rate (Kg/min)	19.7±0.54	10.1±0.45	20.0±0.00	10.0±0.00
Average current (m/s)	0.07±0.00	0.06±0.01	0.04±0.04	0.05±0.03
$\mathbf{Q_{df}}$: Quantity of dry uneaten feed PA (g)	3,711.7±289.8	176.0±8.5	773.3±186.3	27.0±2.6
[2] $\mathbf{R_{uf}}$: Uneaten Feed rate (%)	3.7%±0.3%	0.2%±0.0%	0.8%±0.2%	0.02%±0.0%
Uneaten pellet appearance time (s)	79.6±5.0	77.3±8.7	76.0±3.6	73.8±6.5

[1] Obtained from Equation (2) and set at 100 Kg.
[2] Obtained from equation (3).

Fig. (8) illustrates difference between different feed rates and delivery modes.

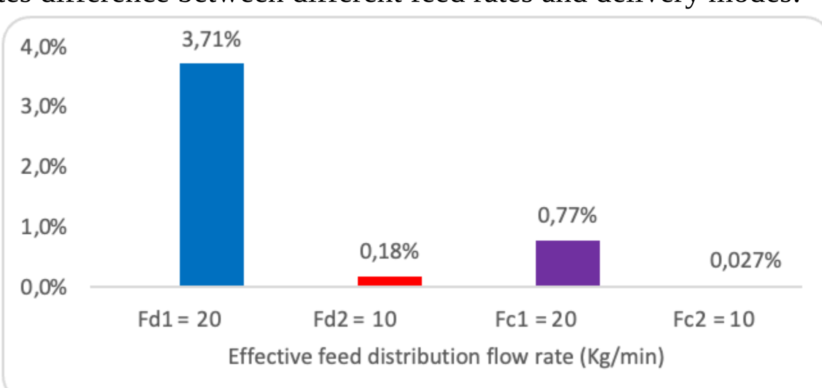

Fig. 8. Uneaten feed rate (Ruf) by distribution flow rate

DISCUSSION

Numerous studies have used different methods to quantify uneaten feed in fish farms: video observation and imagery processing **(Liu *et al.*, 2015)**, setting up collectors **(Ballester-Moltó *et al.*, 2017)** or using echo sounders **(Llorens *et al.*, 2017)**.

Uneaten feed quantification was carried out in the current study using a cover net. Although the method remains laborious and requires great efforts, it has however the advantage of being more accurate, particularly since the bypass net mesh size used was small covering the entire surface of rearing net. This technique allows collecting the total uneaten feed in operating conditions.

Uneaten quantification feed showed that in manual (discontinuous) distribution mode at the fast flow rate (20kg/ min), a higher quantity of uneaten feed was obtained. Slowing down flow rate to 10kg/ min at the same mode distribution reduced lost feed rate from 3.7 to 0.2%. Difference between the two flow rates was statistically significant ($P< 0.05$). Similar findings were observed with pneumatic (continuous) distribution mode, where the two flow rates had uneaten feed rates of 0.8 and 0.02%, respectively; significant difference between the two flow rates was observed in continuous mode ($P< 0.05$).

Comparison of collected uneaten feed rates between the two feed distribution modes (continuous and discontinuous) at 20kg/ min flow rate was statistically significant ($P< 0.05$). In addition, it was statistically significant at 10kg/ min flow rate ($P< 0.05$).

Slowing down feed flow rate had positive impact on feed efficiency for sea bass farming.

Ang and Petrell (1998) compared between different feeding techniques and deduced that, the technique which witnessed lost feed in pneumatically fed cages was easily controllable, whereas in manually fed cages, feed wastage was evident when the rate of feeding was high (1 to 5kg per shovel). In contrast, no pellet wastage was found in cages fed with small feed shovel. Our results confirm that the amount of feed that is not consumed in manual feeding can be reduced by slowing the feeding rate (extending the feeding time).

Feed efficiency improves when feed distribution is uniform and continuous over a longer period. Use of pneumatic cannon allows a continuity of feed distribution and significantly reduces losses rate, compared to manual discontinuous feed distribution, recording a decline from 3.7 to 0.8% and from 0.2 to 0.02% for the flow rates of 20kg/ min and 10kg/ min, respectively.

In addition, feed losses are related to farmed fish feeding behavior and feed intake. Slow, uniform and continuous distribution mode was the most adapted to the feeding behavior of sea bass (*Dicentrarchus labrax*) in Aquamdiq site conditions.

During manual feed distribution, fish swim in different directions and become more aggressive with frequent collisions **(Sarà *et al.*, 2010).** It seems that in manual mode, discontinuity in feed distribution caused by the downtime of manual filling shovels and handling bags create unpredictability feed location. This causes supplementary energy consumption for fish vainly swimming in different directions. At higher flow rate, pellets could escape farmed fish and become uneaten feed lost outside cages.

According to **Talbot *et al*. (1999)**, the manual mode involves a high labor intensity, where rate and size of feed ration depend on feeding personal skills. They added that, if the species is not surface feeding, it may be difficult to assess when farmed fish have finished eating, which may lead to inefficient feeding.

Pneumatic cannon distribution allows, on the other hand, farmed fish to locate distributed feed and causes less stress in searching for feed. An automatic feed distribution, uniform and continuous in the center of the cage, allows a circular horizontal fish swimming behavior around the center of the cage and sudden and continuous vertical micro-movements from the surface to deeper layers and vice versa **(Sarà *et al.*, 2010**; **Papandroulakis *et al.*, 2012)**.

In addition to the impact of distribution patterns however, physical conditions of rearing environment can also influence the rate of feed loss **(Azzaydi *et al.*, 1999; Paspatis *et al.*, 1999; Talbot *et al.*, 1999)**.

Experiments in the present study were conducted under comparable physical environmental conditions since current velocity was relatively low, and difference between average current intensities in these different experiments was statistically insignificant (P>0.05).

The influence of current intensity on feed availability time in the cage was considered in this study. According to divers observations, uneaten feed has totally left the cage form net bottom. Mean of current intensity did not exceed 7cm/ s in all experiments; feed availability duration in the cage, for these low currents, remains very important and allows farmed fish to feed since farmed sea bass speed during feeding time is around 0.85 to 0.9m/ s **(Claireaux *et al.*, 2006; Zupa *et al.*, 2015; Carbonara 2021)**. The longest distance that a fish individual would have to swim in a 12m- diameter and 9m- depth net cage when the feed is distributed in the center of the cage is 9m. Within these dimensions, time required for a farmed fish to cross over is about 10s; whereas in this study, time of feed availability in cage ranged between 73 and 79sec. These times depend on the feed characteristics; feed used in present study experiments was 4.5mm in diameter, which is the most used size for the production of commercial sea bass of 400g. This feed size can represent up to 75% of the total amount of feed needed for a rearing cycle. Feed does not sink for long in cage and leaves it gradually during stronger currents from its lateral sides, and hence the availability time surely decreases.

Several other factors affect feed trajectory at cage level (**Alver *et al.*, 2004**), such as cage shape and farm layout next to other cages (**Klebert *et al.*, 2013)**. In addition, net porosity, flexibility and fooling coverage affect current in and around cages **(Lølland, 1993)**, as well as biomass and movements of fish stocks **(Klebert *et al.*, 2013; Gansel *et al.*, 2014)**. Interaction between these and other factors generates a complex and variable current field around and within cages driving waste trajectory **(Brager *et al.,* 2015)**, forming effects that reduce or, rather, increase the feed availability time in cage.

The observed results highlighted the importance of feeding practices. They have a direct impact on both the productivity and profitability of fish farms and on the environment as well **(Roque d'Orbcastel *et al.,* 2008; Grigorakis *et al.,* 2009)**.

Slowing down feed distribution flow rate allowed us to reduce the uneaten feed by more than 90%, resulting in productivity gains, and subsequently improving feed conversion ratio, leaving a positive impact on commercial margin. Additionally, this practice would allow weaker fish to feed thus improving fish size homogeneity in cage, and consequently reduce the risk of cannibalism.

The present study finds value in its contribution to the reduction of uneaten feed to improve the economic and environmental sustainability of fish farming **(Yokoyama *et al*., 2010)**.

On a larger scale, the world production in 2020 of the European sea bass (*Dicentrarchus labrax*) was 240 674 tons **(FAO-FIGIS, 2020)**. This estimate was aligned with a feed conversion ratio (FCR) of 1.38 **(Besson *et al*., 2019)** and a feed selling price of € 1.5 per kg. A 3% improvement in feed utilization (FCR reduction from 1.38 to 1.34) would save € 14,945,000 for European sea bass production cost in 2020. On farm scale, a 3% improvement in feed utilization productivity would be improved by an increase in marketed biomass and profitability of 3% and a FCR reduction of the same rate. Furthermore, another performance would be improved such as the survival rate through the reduction of cannibalism risk linked to variation rate.

Fish feed cost represents about 50 to 60% of sea bass production cost. Any loss can have a considerable impact on the bioeconomic performance of fish farm due to FCR increase **(Stewart *et al.,* 2012)** and fish growth decrease, which would subsequently lead to a decline in commercial price of fish due to its quality **(McCarthy *et al.,* 1992)**.

Any lost feed reduction should not be overlooked regarding its positive advantage on economic aspects but also for environmental preservation. Intensive fish farming in coastal waters generates large amounts of organic waste in the form of uneaten feed, fecal matter or metabolic waste (urea) **(Roque d'Orbcastel *et al.,* 2008)**. Moreover, this can lead to the deoxygenation of bottom waters, changes in benthic structure and the production of nitrogen and phosphorus compounds **(Pearson & Black, 2000)**. Increased phosphorus can contribute to algal blooms and eutrophication, while large amounts of nitrogen affect water quality **(Cloern, 2001)**. Furthermore, **Wu (1995)** reported that, up to 82% of phosphorus in fish feeds was lost to the environment, and 68 to 86% of nitrogen supplied by feed is eventually released in dissolved form into the water column.

CONCLUSION

Feed losses remain a major problem in fish farming production, both economically and environmentally; an appropriate management helps reduce fraction of uneaten feed and its impacts.

The current study investigated feed flow rate and distribution modes' effects on feed losses in sea bass (*Dicentrarchus labrax*) farming; it contributes to feed optimization and economic management of aquaculture farms.

Uniform and continuous feed distribution has been shown in a more efficient way of fish feeding. Feed flow rate and current intensity can increase lost feed rate resulting in the reduction of feed availability duration in cages.

Further investigations could focus on a longer period to study the impact of a slowed feeding rate on fish growth, feeding efficiency, fish size homogeneity and survival rate. It will also be interesting to study the effect of feeding flow rates in unfavorable environment conditions, especially when currents are stronger to create a practical decision support tool for fish farmers.

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