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Acceptance of insect meal in aquaculture feeding: A stakeholder analysis for the Italian supply chains of trout and seabass

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Abstract

Insect meal could represent an option for partial replacement of fishmeal, the quantity and price of which are a constraint to the expansion of aquaculture. In this article, the acceptance of insect meal as a feed component among Italian farmers of trout and seabass is investigated and discussed. Semi-structured interviews have been conducted with farmers, feed producers, and insect-meal producers. Then, a deductive thematic analysis has been carried out to understand which of the different variables characterizing farming structures and marketing channels can affect the choice of feed products and, as a consequence, the acceptance of insect meals. The information collected suggests to differentiate two levels of insights: the first concerns plain economic evaluation in what could be considered a standardized or theoretical environment, and is mainly related to the feed price and the feed conversion ratio. The second level takes into consideration the effects that occur in real environments and that are different depending on farm characteristics and business choices. Among the main aspects that should be considered (beyond prices and feed conversion ratio) are the final destination of the product, the processing and large retailers' requirements, the effects on digestion and feces production, and the variability of performance (as an effect of feed nutritional variability and environmental variability).

KEYWORDS
European seabass, feed conversion ratio, insect meal, rainbow trout, supply chain

1 | INTRODUCTION

Due to the limited resources available from the sea, if aquaculture wants to continue its expansion process, supplementation of new feeding products for partial replacement of fishmeal is required. Insects can be considered one of these substitute products (Le Féon et al., 2019). Compared to vegetable substitutes such as soymeal, insects produced on organic waste substrates and by-products require little energy and water, leave a small ecological footprint, and have a limited need for arable land (Oonincx & de Boer, 2012). Furthermore, they contain high levels of essential amino acids (Henry, Gasco, Piccolo, & Fountoulaki, 2015).

In 2011, the European Union (EU) Parliament adopted a resolution to address the EU's protein deficit, stating that urgent action was needed to replace imported protein crops with alternative and additional European sources. Commission Regulation (EU) 2017/893, applied from July 1, 2017, amending previous regulations, authorized the use of products derived from seven insect species[1] for feeding aquaculture animals. Before that date, in the first years of the millennium, the research community had already begun to investigate the potential use of these species. Nowadays, the sector of insect meal (and insect oil) production is in its initial phase of development, characterized by a large number of small enterprises in competition to improve the production efficiency of their plants and the quality of their products. Between July 2017 and October 2018, roughly 1,000 tons of insect protein have been commercialized by European insect producers, half of which is used for aquaculture feeds (IPIFF, 2018). In an article on FeedNavigator.com (October 25, 2018), the product development director of fish feed producer Skretting said that "Skretting engaged with over 30 [insect meal] manufacturers, and ended up with a handful of suppliers"; and "ideally, by 2022, there would be at least five different European suppliers, each producing 20,000 tons of insect meal per year" (Byrne, 2018).

The objective of this article is to assess the stakeholder acceptance of insect meal use in aquaculture feeding on the basis of economic and technical feasibility. In particular, this will be evaluated for the Italian market through qualitative semistructured interviews with feed producers and trout and seabass farmers. The study aims to evaluate if, besides strictly economic considerations linked to the feed price and the feed conversion ratio (FCR) (i.e., pure economic feasibility), there are other elements that can affect stakeholders' acceptance (i.e., technical feasibility). Since inside the trout and the seabass farming sectors, relevant differences can be found at structural and marketing levels, we are particularly interested in verifying how these differences may affect the acceptance of new feed formulations. Technical aspects emerge from the combination of farmers' needs (linked to structural assets and marketing strategies) and feeds' characteristics, meaning some products may not be used under specific conditions, or could require expensive changes in the business models adopted by firms.

This article is structured as follows: In the next section, the background of the current situation is illustrated; it begins with some considerations on the sustainability dimension of insect meal production, then it focuses on the main aspects related to the economic and commercial profitability of fish farming using feeds with insect meal; finally, the structure of Italian aquaculture is presented. In Section 3, the methodological approach is illustrated. Section 4 deals with the results collected through the interviews with insect meal producers, feed producers, and farmers. Section 5 discusses the possible acceptance of insect meal based on farming characteristics, and Section 6 concludes the article.

2 | BACKGROUND

2.1 | The sustainability dimension of insect meal production

In the last years, insect farming for the food and feed industry has dramatically increased worldwide (Madau, Arru, Furesi, & Pulina, 2020). Insects are very rich in fat, vitamins, and minerals and are highly able to efficiently convert embedded energy from organic matter to high-value edible proteins useful for animal and human diets (Collins, Vaskou, & Kountouris, 2019; Diener, Solano, Gutiérrez, Zurbrügg, & Tockner, 2011; Diener, Zurbrügg, & Tockner, 2009; Roma, Ottomano Palmisano, & De Boni, 2020). Feed conversion rate is high, water is directly obtained by feed, and the use of land is reduced. In conclusion, insect farming can decrease natural resources utilization, with the same amount of proteins produced, if compared to other animal productions (Borrello, Lombardi, Pascucci, & Cembalo, 2016; Mancini et al., 2019; Schlup & Brunner, 2018; van Huis, 2012).

Among others, insect breeding allows efficiently recycling of some resources such as the waste derived from agricultural practices and from agroindustry (Govorushko, 2019; Orsi et al., 2019). Attempts to estimate sustainability in terms of ecological footprint, water footprint, or life cycle assessment confirm the low environmental burden compared with other animal production activities (Oonincx & de Boer, 2012; Roffeis et al., 2018; Smetana, Palanisamy, Mathys, & Heinz, 2016).

2.2 | The economic aspects of insect meal use for aquaculture

Several articles have reviewed the potential of insects as feed (Makkar, Tran, Heuzé, & Ankers, 2014; van Huis, 2012) and in particular as a replacement of fishmeal in aquaculture (Henry et al., 2015; Nogales-Mérida et al., 2019; Tran, Heuzé, & Makkar, 2015). These articles include effects on growth and also effects on physical and organoleptic characteristics of meat as well as on consumer acceptance.

Literature on replacement of fishmeal with insects has shown promising, but mixed results (Henry et al., 2015). In the case of rainbow trout, some scholars report that 25% to 50% fishmeal replacement provided the same performance on weight gain compared to fishmeal-fed trout (Gasco et al., 2014; Gasco et al., 2014; Renna et al., 2017), while in others reported a decrease (Sealey et al., 2011). St-Hilaire et al. (2007) observed growth reduction for 50% fishmeal replacement, but not for 25%. Differences are found depending on the insect species used, the most typical being mealworm, *Tenebrio molitor* (Gasco, Belforti, et al., 2014; Gasco, Gai, et al., 2014) and black soldier fly prepupae, *Hermetia illucens* (Renna et al., 2017; Sealey et al., 2011; St-Hilaire et al., 2007), and also depending on the insect's life stage, fat content, rearing substrate, processing techniques, and fish life stage (Renna et al., 2017). Compared to other insects, black soldier fly shows an essential amino acid (EAA) profile that is very similar to fishmeal (Henry et al., 2015). Renna et al. (2017) highlight that, beside survival and growth performance, even condition factors, somatic indices, and dorsal fillet physical quality parameters of rainbow trout were not affected by fishmeal replacement.

Experiments realized on European seabass, *Dicentrarchus labrax* are less common. Gasco, Belforti, et al. (2014) and Gasco, Gai, et al. (2014) show that a 25% replacement of fishmeal using mealworm (all diets being isoproteic) has no adverse effects on weight gain, while at 50% level reduction in growth is observed. On the contrary, Magalhães et al. (2017), using black soldier fly pre-pupae meal to replace 15%, 30%, and 45% of fish meal, observed no differences among groups in growth performance or feed utilization. Trials were also carried out on seabass juveniles to evaluate the effects of dietary inclusion of a full-fat mealworm larvae meal, conducting to a worsening of final body weight, weight gain, specific growth rate, and feeding rate (Gasco et al., 2016).

A few studies can be found on consumer acceptance of farmed fish fed on insect meal. In Italy, a research indicates that "almost 90% of consumers have a positive attitude to insect meal as feed" so that no substantial changes in purchases should occur (Mancuso, Baldi, & Gasco, 2016). The results of a research on consumer attitudes in the

United Kingdom, toward the incorporation of insect larvae (maggots) into fish feeds for the Scottish salmon farming sector, were very similar, indicating that only 10% of consumers were opposed to insect meal. However, consumers are not willing to pay a higher price for insect-fed products (Popoff, MacLeod, & Leschen, 2017). A study on German consumers indicates that most of the respondents are indifferent regarding the use of insect-based protein as feed in trout production; however, there is a minor sensitive segment (23%), for which consumption would be expected to be reduced unless the fish price is reduced (Ankamah-Yeboah, Jacobsen, & Olsen, 2018).

Borgogno et al. (2017) used a panel of 10 Italian fish consumers and stated that replacing fishmeal with black soldier fly larvae meal on rainbow trout significantly affects fillets sensory profile including changes in perceived intensity of aroma, flavor, and texture descriptors. On the contrary, another experiment conducted by Sealey et al. (2011), always concerning black soldier fly larvae meal on rainbow trout, attests that no significant difference was detected by 30 untrained panelists in the United States. Researches have been conducted to evaluate the effect of insect meal on the amino acid composition of flesh, considering that this aspect can be linked with fish digestive pathways and flesh quality (Iaconisi et al., 2019).

Popoff et al. (2017) conducted semi-structured interviews with several industry stakeholders of the Scottish insect-feed-aquaculture value chain, in order to analyze their awareness, knowledge, and attitude to new feeding possibilities for farmed fishes. The first conclusion is that consistent quality at a competitive price is required inside the supply chain in order to replace current protein sources in feed. However, the retail sector may have ambivalent attitude, since it would have to be confident of the market for insect-fed fish before embracing it. For Mancuso et al. (2016), the production of insect meals of a constant and defined quality (which highly depends on the constant characteristics of the rearing substrate) is absolutely required by the feed industry.

2.3 | The Italian aquaculture structure

Italy produces approximately 150,000 tons of aquaculture products per year, of which clams and mussels represent 67%. If we only consider finfish, trout and seabass represent the first and second product, with yearly productions of 35,000 and 6,300 tons, respectively. Italy is the largest EU producer of trout (around 18% of EU production) and the third of seabass (around 12% of EU production) (Eumofa, 2019). Additionally, Italian production of feeds for aquaculture is around 135,000 tons (Assalzoo, 2018).

For the Joint Research Centre (Nielsen, Guillen, & Carvalho, 2016), the aquaculture Italian sector can be divided into a few main segments on the basis of species and technologies. Thus, for trout farming, two segments are recognized, "trout on-growing" (Tg) and "trout combined" (Tc), while for seabass and seabream three segments are considered: "seabass and seabream cages" (Sm), "seabass and seabream combined" (Sc), and "seabass and seabream on-growing" (Sg). The trout sector counts of 173 firms, most of them located in the north of the country; firms engaged in seabass production are 51, mainly located in the center end south of Italy. Tg enterprises are, on average, larger than Tc. In the seabass sector, Sm enterprises are the largest ones; on the contrary, only eight very small firms are included in the Sc category.

The operating costs per unit of production are around €2.5/kg for the trout (no large differences are found between Tg and Tc), €6.9/kg for seabass and seabream in cages, and €7.6/kg for seabass and seabream on-growing. Feed cost share on operating costs is around 60% for trout and around 30–35% for seabass and seabream (all data are elaborations based on Nielsen et al., 2016).

In an older study realized by the Italian Institute for Agro-food Market Services (Ismea, 2009), the sector is segmented with more details, considering structural, technological, and even strategic variables. Thus, trout farming includes combined (T1), hatcheries and nurseries for repopulation (T2), on-growing with well water (T3), on-growing with other water (T4), more farming sites (T5), and vertically integrated farms (T6). On the other hand, seabass and seabream farming includes extensive farming (S1), inshore on-growing (S2), cages (S3), and hatcheries and nurseries (S4).

According to this research T1, T2, and T3 are characterized by small farms (<5 ha), with familiar management, while the other segments are larger and with entrepreneurial structure (Ismea, 2009). However, T3 (on-growing with well water) is the technology that allows the highest density of production per volume of water (20–25 kg/m^3), the shortest farming length (14 months) and the best conversion rate of feeds (1.0–1.1). On the other hand, T4 (on-growing with other water) appears to be the most cost-efficient technology (operating costs per unit of production around €1.87/kg). T5 and T6 are represented by no more than 20 firms, but they supply 60% of Italian trout production.

For all trout segments, operating costs per unit of production (€1.87–2.09/kg) are a little lower than figures derived from Nielsen et al. (2016) (€2.4–2.5/kg). Feed costs represent the highest operating expenditure (56–68%) and are in line with Joint Research Centre (Nielsen et al., 2016) statistics (58–62%). The FCR is calculated between 1.0 and 1.1 (for T3 and T5) and 1.3 and 1.5 m (for T2) (Ismea, 2009).

In the case of seabass and seabream, the extensive farming (S1) represents a specific case that cannot be compared either with other systems or with Joint Research Centre (Nielsen et al., 2016) statistics. Operating costs of S2 (€5.6/kg) are higher than S3 (€4.6/kg), as emerged in Nielsen et al. (2016), but in both farming systems, figures are much lower than those calculated by the Joint Research Centre; on the contrary, feed share on operating costs is much higher in cages (48%) compared with inshore growing (37%). The FCR is calculated around 1.85–2.5 for S2 and around 2.25 for S3 (Ismea, 2009).

3 | METHODS

Three questionnaires were prepared: one for firms that produce insect meal suitable for fish feeding; one for fish feed producers; one for trout and seabass farmers (see three questionnaires in the Appendix). Nine firms, producing insect meal located both inside and outside the EU, were contacted via email. However, mainly due to the confidentiality of information, only two accepted to answer. Direct semi-structured interviews were conducted with the technical and executive personnel of two of the largest feed factories of Italy, with six trout farmers and with four seabass farmers.

The choice of the farming enterprises has been realized with the objective to cover, with a small quantity of effort, money, and time, a large diversity of farm structures and business models. Thus, keeping in mind the classification realized by Ismea (2009), we have chosen six trout farmers and four seabass farmers with the following characteristics. Among the six trout farmers, yearly production ranges between 15 and 800 tons, mainly of rainbow trout, *Oncorhynchus mykiss* and in minor quantities brown trout, *Salmo trutta* and arctic char, *Salvelinus alpinus*. Two firms have more than one farming site (all characterized by different conditions of water origin, temperature, and oxygen needs). Three farms are vertically integrated, since they process several kinds of trout products. All farms can use surface waters, but two have also access to wells. Two farms only carry out on-growing stages, while four are combined farms.

In the case of seabass production, all firms have inshore tanks, but two also have offshore cages; in these cases, separate interviews for the two systems have been conducted. All farms are on-growing, buying fingerlings from specialized companies. In fact, as attested by the Joint Research Centre (Nielsen et al., 2016), only a few firms are able to conduct a combined seabass production. Production ranges from 440 to 1,600 tons per year. Seabass represents from 50% to 70% of firm production, being the remaining part represented by seabream (Table 1).

For the objectives of this article, it was not important to classify each of the 10 firms inside specific groups. In fact, a clear classification is not feasible (e.g., there are trout farms that have more farming sites and are also vertically integrated; water can be taken from different sources; seabass can be farmed both in tanks and in cages). Much more important is to understand, through the conversation with farmers, which of the different variables characterizing farming structure and marketing channels can affect the choice of feed products and, as a consequence, the acceptance of insect meal.

TABLE 1 Main characteristics of the firms considered in the study

Firm	Size	Farming sites	Processing	Main buyers	Fish density	LAP
Trout1	Medium	Several	Yes	Retailers, wholesalers, cooperatives	Medium	Yes
Trout2	Medium	One	Yes	Retailers, wholesalers	Medium	Yes
Trout3	Small	One	Yes	Specialized markets	Low	No
Trout4	Medium	One	No	Fishing lakes, processors	High	Yes
Trout5	Small	One	No	Fishing lakes, restaurants	Medium	Yes
Trout6	Medium	Several	No	Retailers, wholesalers, cooperatives, processors	Medium	Yes

Firm	Size	Farming systems	Seabass share
Seabass1	Medium	Inshore	50%
Seabass2	Medium	Inshore	70%
Seabass3	Large	Inshore and offshore	60%
Seabass4	Large	Inshore and offshore	70%

Note: Farming size: small < 50 tons/year. Fish density: low < 15 kg/m^3; high > 40 kg/m^3. LAP: Use of feeds containing proteins derived from land animal products. Farming size: medium < 500 tons/year.

Thus, when interviews have been analyzed, a theoretical (or deductive) thematic analysis has been carried out (Braun & Clarke, 2006), using the following approach (see Table 2):

1. Specific characteristics of farms have been coded, including structural and marketing patterns.
2. Specific attitudes, choices, and problems related to feeding have been coded.
3. Relationships between farm characteristics and feeding patterns have been identified.
4. Theoretical consequences on economic and technical feasibility of insect meal adoption have been inferred using a deductive process (see discussion).

4 | RESULTS

4.1 | Feed producers and insect meal producers

According to a firm's responsibility for the development of aquaculture feeds, insect meals produced by European enterprises can be considered of good and standardized quality; however their cost (from €3.5 to €7/kg, around 60–70% protein content) is not competitive yet. Interviews with feed producers and insect meal producers indicate that products coming from other continents (Africa and Asia) are available at a much lower price (between €1.2 and €2.5/kg, around 55% protein content). However, for EU feed producers, it is too risky buying products (from outside the EU) that have no certification or guarantee of standardized quality. Non-EU insect meal producers recognize that lack of confidence in food safety is one of the main problems to be solved. Producing sufficient quantities to lock-down offtake agreements is another problem that needs to be solved. Prices of European insect meal, however, is expected to decrease in the next years; one producer estimates that price will be 30% lower in 2030, thanks to improved technologies and economies of scale.

Interviews reveal that in 2018, fishmeal price was between €1.3 and €1.6/kg (2018), depending on protein content (60–66%). Other proteins derived from land animal products (LAPs) result to be much more competitive than

TABLE 2 Relationships between farm characteristics, feed choices, and possible consequences on insect meal acceptance

Species	Farm characteristics	Feeding pattern	Quote	Consequences on insect meal acceptance
Trout				
	Production quantity and intensity			
	Niche production, low density	High fishmeal%, expensive feeds, no LAPs	"I refused contracts with large retailers"	Price can be high; feeds must guarantee high quality; problems for testing
	High intensity	Cheap feeds, FCR matters	"Price and FCR are the main drivers"	Insects' feeds must be very cheap with high FCR
	Average intensity	High FCR, efficiency	"Feed price matters, poultry waste is a good raw material"	Insects' feeds must be more efficient than LAPs
	Processing			
	Integrated farm	Effects on fat deposition, fillet yield, meat texture	"Feeds may affect fillet yield and meat texture"	Insects' feeds must guarantee good organosomatic indices
	Nonintegrated farm	Small consideration to processing	"I don't think feeds may affect fillet yield and meat texture"	None
	Farms with different water sources	No differentiation of feeds but avoidance of feeds with very high theoretical FCR.	"It would be too complicated to take account of this variable" "Performance of feeds with very high FCR is guaranteed only if environmental conditions are perfect"	Check how insects feed is affected by different environmental conditions and health of fishes. Constancy of yields is required.
	Generalized patterns	Complains on feed quality	"FCR is not constant; ingredients change"	Attention to insect meal chemical composition
		Effects on feces and water quality	"Some feeds dirty water more than others, having effects on health"	More attention to effects on feces, water and fish health
			"I don't care visible effects because there are more invisible contaminants"	Less attention to effects on feces and visible contaminants
Seabass				
	Technology			
	Cages	Avoidance of expensive feeds	"Very expensive feeds are not indicated, since dispersion is higher in cages"	Price should not be too high for offshore use
		Same feed of seabream	"There are too many complications in using different feeds for seabass and seabream"	Performance should be good also for seabream
	Generalized patterns	Sometimes use of feeds with lower price and FCR	"This can be necessary to decrease growth, when there is no market, or when fishes are not in good health"	Alternative use of feeds based on insect meal depending on price and FCR

TABLE 2 (Continued)

Species	Farm characteristics	Feeding pattern	Quote	Consequences on insect meal acceptance
Both				
	Buyers			
	Large retailers	Protocols to be followed, LAPs never allowed for seabass	"Some large retailers are more demanding than others for trout"	Insects must be included in raw materials permitted by protocols; insects must be more efficient than LAPs if these are permitted too
	Generalized patterns	More feed companies as providers	"Having more providers is useful for credit"	None
		Problems to test feeds	"It is too expensive and complex to perform reliable tests"	Problems for the introduction of new products (unless they are very cheap)

both fishmeal and insect meal. Among these, there is poultry meal and blood meal (prices between €0.6 and €0.7/kg; protein content between 66 and 84%), while a little more expensive is hemoglobin. Vegetable meals (including soya bean and other leguminous meals) are even less expensive (€0.4–€0.7/kg, with protein content between 30 and 60%); prices of corn and wheat gluten are, on the contrary, higher (0.8–1.6 €/kg, with protein content between 60 and 80%).

Interviews also indicate that average unitary costs of commercial feeds are mainly related with two variables, which are the presence of LAPs for a partial substitution of fishmeal (i.e., feeds with higher fishmeal percentage are more expensive[2]) and the FCR (i.e., feeds with lower FCR are more expensive).

4.2 | Trout farmers

Trout farmers indicate an average unitary cost of feeds used during the growing life stages between €1.15 and €1.7/kg. FCR is between 1.15 and 2. Duration of growing is around 12–14 months for 300–400 g trout, and around 18 months for 600 g trout. These figures are coherent with data collected from feed producers. Sale price of fresh (white) trout can range from €2.8 to €5/kg (mainly depending on marketing channels) and is not affected by fish size. Fish size normally ranges from 300 to 700 g, depending on buyer's needs. Production of salmon trout is also very common. Three farms produce several preserved and processed products, including fillets, marinated, smoked, ready-to-eat products, and eggs.

In the following sections, the main patterns concerning feed use are indicated and associated with the structural, technical, and marketing characteristics of farms (see Table 2). In other words, we will try to understand how farming structures and business models can affect the choice of specific feeds.

4.2.1 | Niche production versus mass production

Interviews reveal that average unitary cost of feeds is not strictly (i.e., inversely) correlated with FCRs measured at plant level. In particular, small (familly) farms with niche production (of both fresh and processed trout products) for selected markets (small retailers of high value products, weekly markets), where high feed unitary cost (€1.7/kg) is associated with less intensive production systems, longer growing periods (up to 36 months), higher size (>800 g) and, to compensate all previous elements, higher trout prices (€5/kg for fresh white trout. In comparison, other producers indicate a price between €2.8 and €4/kg). This kind of farm does not sell its products to large retailers since these contracts are considered not attractive for them (i.e., contracted prices are too low). Feeds used do not contain LAPs and have lower fat content than most common products, since the farmer wants to use feeds that are considered of very high quality, to obtain meat of the best texture and taste. Consequently, FCR is very high, around two.

On the opposite side, we find large and intensive farms (50 kg/m^3), which only sell fresh (or live) products, that use the less expensive feeds to produce small size (300 g) trout at lower price (€2.8/kg). Production is sold either for human consumption (mainly to fish processors) or for repopulation of fishing lakes. For this kind of farms, FCRs are also relatively high (around 1.3), but not as high as small niche farms. Unitary feed cost is low, around €1/kg.

Finally, farms with average trout densities (20–25 kg/m^3) register FCRs between 1.14 and 1.22, while feed unitary costs are between €1.15 and €1.3/kg.

Considering all previous figures, the feeding cost for the production of 1 kg of fresh white trout is between €1.4 and €2.5, with a weight of feeding costs on trout price ("feed cost per kilo/trout price per kilo" ratio) between 44 and 54%. Interestingly, the highest feeding cost ratios are found for both niche farms (where feeding prices are very high) and large intensive farms (where trout prices are low), while the lowest feeding cost ratios are found for farms using average feeds (in terms of price and FCR) and average intensity.

4.2.2 | Processing and final destination

Price and FCR are clearly among the main variables that farmers consider when they purchase feeds. However, feeds sold by the main feed companies have no large differences in these aspects, thus some farmers (but not all) consider that other characteristics are quite relevant for decision-making.

Farmers who directly process trout to produce fillets seem to be particularly careful to the effects that different feeds can have on organosomatic indices (e.g., the relation between size and length), fat deposition, fillet yield, and meat texture. The organoleptic characteristics of the fish seem to be less important. Integrated producers have tested different feeds in order to find the best solutions for their needs. On the contrary, farmers who sell whole fresh fish do not consider these elements to be very important (in particular fillet yield) or do not think feeds can considerably affect these characteristics.

The final destination of trout is also relevant for the choice of feeds. Most of the farmers use mixed commercialization strategies, since trout can be purchased by a large set of buyers, including large retailers, wholesalers, small retailers, final consumers, restaurants, repopulation authorities, and owners of private lakes. Whole fresh trout, in particular, can be purchased and sold by large retailers under their own private labels. In this case, farmers have to follow specific protocols for trout production, including a list of feed raw materials that are allowed. A few large retailers (but not all) do not permit the use of LAPs. Similar obligations exist for farmers who want to apply for the halal certification. Trout for processing products can also take different routes. In Trentino area, for example, where we find a large concentration of farmers, trout can be processed by the farmer, by local specialized processing plants, or by a large farmers' cooperative. Also in this latest case, trout that is sold using the cooperative label has to be farmed following a specific protocol, including feed characteristics (insects now are not contemplated). Several feed firms are now producing feeds specifically for this cooperative, using a formulation that is not commercially available for other farmers.

It is clear that, depending on the farm size and the business capacity that firms have to manage different production lines, farmers have to choose between using feeds that are allowed for all destinations (generally, the most expensive), separating production lines or renouncing to specific destinations.

4.2.3 | Water temperature and quality

Several farmers agree that some, relatively expensive, feeds may have very good conversion ratio performances (i.e., FCR < 1). However, these performances are guaranteed only with perfect conditions of temperature, water quality, genetic quality, and well-being of fish. Since these conditions cannot be assured, these products are normally avoided.

Since most of the firms catch water from different sources, farmers are normally aware that FCR is affected by water temperature (one farmer indicated an FCR of 1.15 in plants where water temperature is relatively constant, and 1.3 where temperature range from 0 to 20°C). Farmers recognize that, theoretically, water temperature could affect the choice of the best feed; however, this aspect is rarely considered, since variables affecting choice are already quite complex.

One characteristic of feeds that is considered of particular importance by most of the farmers is the effect they have on digestion and on the quantity and quality of feces. In fact, some substances may be toxic and affect the wealth and growth of trout. Farmers tend to select feeds based on the "visible" effects they have on feces production. However, there are farmers that think that "invisible" substances may be more relevant than "visible" feces.

4.2.4 | Other variables

Trout farmers appear particularly sensitive to variability in feeds performance. Most of them believe that some feed producers use to change raw ingredients and this affects the yield. This lack of stability has been, in the past, one of the main reasons of complain and change of provider.

Feed producers interviewed for this analysis recognize that some international feed industry (especially the largest ones) could change raw material inside of specific feeding products, taking advantage of price fluctuations. Others prefer to maintain ingredients as constant as possible. According to feed producers, trout farmers still remember the effects of some formulation problems occurred in the past, and continue thinking that this can happen again. For this preconception, farmers would not be able to recognize the variability linked to other factors (including atmospheric conditions, quality of water and fingerlings, and occurrence of diseases).

Finally, it must be said that most of the farmers prefer to use feeds from different providers, generally two or three. Several strategic reasons, beside technical factors, justify this behavior, including the possibility to obtain more credit (i.e., delayed payments) by several feeding firms, the benefit from discounts, the extension services provided, the availability and quickness of delivery, and the existence of specific contracts that include the purchase of trout production.

4.3 | Seabass farmers

Differently from trout, seabass price changes considerably with size. Price is around €8/kg for the 300–500 g size grown inland, and gradually increases reaching more than €11/kg for sizes over 1,000 g. Sizes between 500 and 800 g are the most common. Producing large size (>400 g) is necessary to avoid the competition of products imported from Greece and Turkey, which mainly export fish under 300 g with prices around €2.4/kg. The value of seabass grown in cages is sensibly lower (€1–€1.5/kg less) than seabass grown inland; this is mainly due to the fact that skin of seabass grown in cages is clearer and less appreciated by consumers.

Seabass farming obviously presents relevant structural difference between inshore plants using tanks and offshore cages; however, in terms of characteristics of the final product, seabass (compared with trout) presents much more characteristics that are common to all producers. In particular, seabass is almost exclusively sold as whole and fresh (there are no processing stages), large retailers represent the main buyers, and all require very similar protocols where LAPs are not allowed for feeding; finally, sizes must be large in order to avoid competition from abroad.

For these reasons, all producers choose feeds that are quite similar in terms of composition (e.g., for the growing stage, around 43–45% protein; 18–21% fat; 30% fishmeal), price (between €1.1 and €1.25/kg) and FCR (between

2 and 2.3). Duration of growing is around 21 months for fishes of 400 g and increases until 36 months for fishes around 2000 g.

Choosing feeding products with lower prices and lower FCRs (i.e., lower fishmeal content and/or lower fat content) can be useful to slow the growth when there are no orders from buyers, or when fishes are not in good health. Very high fat content (24%) is also avoided for inland production, since these feeding products increase the concentration of catabolic substances in the water; they could be adopted more easily in cage farming, but expensive feeds are not recommended for cages, where dispersion is higher.

Seabass and seabream may prefer different feeds. However, especially for cages at sea, it is often necessary to renounce to use differentiated products, since this would increase logistic complications for transport and distribution.

There are cases where farmers deliver seabass to a local cooperative, which sells it (whole or fillets) under a common brand or as an intermediary for large retailers. In this case, all farmers delivering fish have to follow the same guidelines for feeding. Feeds are specifically produced by feeding industries for the cooperative using a formulation that is not available on the market (fish oil content is higher than other feeds). Good marketing strategies, including a recognized geographical brand and good quality of fish (e.g., large size, high level of Omega-3 content), allow selling products at prices that are €1 higher than Italian average.

In general, the decision of large retailers to forbid LAPs is considered negatively by farmers, which see these products very suitable to substitute fishmeal, and better than vegetable meals.

In addition to trout farmers, seabass farmers prefer to use feeds from different providers (two or three). However, feed producers indicate that, in the case of seabass (and seabream), it is more common to have contracts that establish a scheduled delivery of feeds. On the contrary, trout farmers are more prone to occasional orders. Finally, most of the farmers, for both species, notice that it is very difficult to realize reliable tests to compare new typologies of feeds, since many variables may affect the results and a lot of space would be needed (small trials are not significant). This limit can affect considerably the adoption of innovative feeds. In the trout segment, similar concerns were very widespread when poultry meals appeared, but low costs incentivized their adoption, and poultry meal is now very common for most of the trout feeds.

5 | DISCUSSION

Information collected from insect meal producers, feed producers, and trout and seabass farmers provide several indications about the possible acceptance of insect meal by the stakeholders of the supply chain. We differentiate two levels of indications: the first concerns plain economic evaluation (i.e., pure economic feasibility) in what we could consider a standardized or theoretical environment, and is mainly related to the price of raw ingredients (and, as a consequence, the price of feeds), to the FCR and (potentially) to the price of fish produced with different feeds. The second level takes into consideration of the effects that occur in real environments; these are different depending on farm characteristics and business choices and are related to aspects concerning both economic and technical feasibility. Technical aspects emerging from farmers' needs imply that some products may not be used under specific conditions or would require expensive changes in the business models adopted by firms. Some of these technical requirements are objective (i.e., large retailer protocols), others respond to farmers' beliefs, more or less motivated, such as the effects of feeds on feces and (consequently) on fish health.

5.1 | Theoretical evaluation of economic aspects

A theoretical evaluation, where the effects of different diets are compared, could consider three different scenarios depending on the business and marketing constraints of fish farmers:

1. Farming period length is maintained constant, where diets only affect the final size of fish.
2. Fish size is maintained constant, where diets affect the quantity of feed used and/or the time of growth.
3. Farmers have no constraints and can choose the strategy that maximize their profit.

These three situations require slightly different approaches to find a solution. However, the three situations can be simplified and brought back to a general framework if we assume (as most of the scientific literature affirms) that feeds where half of the fishmeal is substituted with insect meal should maintain the same FCR and guarantee the same growth rates,[3] and if we assume (as most of the marketing literature affirms) that the use of insect meal should not affect consumer preferences. In this simplified case, the only variable relevant for the comparison of two diets is the price of the feed.

As attested, in Italy, fishmeal price was around €1.3/kg in 2018 for a 60% protein content. Trout feeds without LAPs may contain 30% of fishmeal and have prices around €1.3/kg. Current prices of insect meal produced by EU firms is currently no less than €3.5/kg.[4] Thus, 50% replacement of fishmeal with insect meal would cause a 25% increase of the feed price (around €1.63/kg). Furthermore, feeds that contain insect meal would be in competition with feeds that already (partially) replaced fishmeal with LAPs. For example, feeds containing only 15% of fishmeal (replaced by hemoglobin and poultry meal) and with FCR similar to feeds without replacement, only cost €1/kg.

Similarly, seabass feeds without LAPs may contain 30% of fishmeal and have prices around €1.2/kg. Thus, 50% replacement would cause a 28% increase of the feed price (around €1.53/kg). Feeds containing only 10% of fishmeal (replaced by LAPs, with FCR similar to feeds without replacement) only cost €1/kg.

If we consider that feed costs weight about 45–55% of the revenue for trout and about 27–32% for seabass (figures confirmed by Joint Research Centre (Nielsen et al., 2016) data and by data collected with farmers), it is clear that even small increases in feed price may affect the profitability of the activity, especially for trout.

However, things can change quickly in the next years. Fishmeal price, in particular, is strongly affected by catches in Peru, which are unpredictably linked to El Niño–Southern Oscillation phases. In the latest 10 years, the international fishmeal price has constantly fluctuated between US $1.29 and $1.92/kg[5]; in the same period, the fishmeal/soybean[6] meal price ratio fluctuated between 2.6 and 5.4 (IndexMundi, 2019). Given the substantial rise in demand in both aquaculture and livestock production, the price of fishmeal is expected to increase in the next decade and the meal selectively allocated for the production of high-value products (OECD-FAO, 2018; World Bank, 2013). On the other hand, insect meal producers estimate that the price of insect meal will decrease quickly in the next decade.

5.2 | Effect of farm structures and business choices

Interviews carried out for this research have shown that differences in farming structures and business models strongly affect feeding choices due to economic and technical motivations. This could also affect the acceptance of new feeds containing insect meal (see Table 2).

Trout farmers that produce high-value products for market niches (and not for large retailers) and use expensive feeds without LAPs could be, in theory, the first ones to try feeds containing insect meal, when prices will begin to decrease. They could also take advantage of an image of sustainability, since insect meal used as a substitute for fishmeal would decrease pressure on marine resources. However, insect meal should guarantee the same quality of trout meat (including organosomatic indices, fat deposition, and fillet yield and meat texture). More in general, these characteristics should be guaranteed to all the farmers who are personally engaged in trout processing. On the other hand, we have seen that niche producers may coincide with small farms, and this could cause resistance toward new feeds, since farmers cannot realize significant trials to test them.

Larger farms may have less problems to perform trials. However, large farms that mainly address their production to large retailers (almost) all use feeds containing LAPs. This means that insect meal price should further decrease in order to be a competitive product. The most difficult trout sector to be reached deals with farms that use very intensive technologies and cheap feeds (mainly for the repopulation of fishing lakes). These farmers could adopt feeds containing insect meal only if they show very competitive FCRs.

Maybe, the best opportunity of initial acceptance for insect meals is related with farms that produce trout for those large retailers that do not allow the use of LAPs. The same argument is true in the case of seabass, where no large retailer allows LAPs. It is clear that a prerequisite for the success of the new feeds is that large retailers change their protocols and include insect meal among the permitted raw materials. However, it cannot be excluded that, when new protocols are discussed, LAPs could also be included, since pressure in this direction from both farmers and feed producers is very high.

Other elements that should be considered and could facilitate (or not) the acceptance of insect meals in inshore basins concern the effects on the quality of water (especially the visible effects). On the other hand, acceptance for offshore farms could be more complicated since expensive feeds are not appreciated (due to higher dispersion rates), and the new feeds should result optimal for seabream too.

Finally, it is essential that the new feeds based on insect meal maintain unvaried properties and FCRs without differences between lots. Even if feed producers are resolute to state that similar problems do not occur anymore, farmers (especially trout farmers) continue to be very sensitive to any (apparent) difference in feed performance, alerted by problems that occurred in the past. This element should be carefully considered in the case of insects, since non-homogeneous conditions of growth (i.e., several raw materials could be used for rearing) could affect the nutritional properties of the meal. Furthermore, it would be necessary to test how feed properties (in particular FCR) are affected by different environmental patterns and health conditions of the fish. Constancy of performance and yield is normally preferred rather than situations where a feed can guarantee high FCR only if all conditions are perfect but cause problems when small changes in the environment occur.

6 | CONCLUSIONS

Insect meal may represent an option for a partial replacement of fishmeal, the quantity of which is a constraint to the expansion of aquaculture. This research on Italian farmers confirms that feed price and FCR remain the most important drivers for the adoption of new feeds. Currently, insect meal price is not competitive compared to fishmeal, and even less compared to proteins derived from LAPs. However, insect meal producers and feed producers seem to be very confident that insect meal prices will decrease quickly in the coming years. This price gap would be less problematic if fish fed with insects could be sold at higher prices, promoting it as a more sustainable product.

Italian farmers have no prejudices toward new raw ingredients (including insect meal) for feeding. However, since they had negative experiences with new feeding products in the past, and since they cannot efficaciously test new feeds in their local context (due to the limited extension of farms), they are always very cautious to accept novelties. The case of LAPs, which are now commonly accepted and would be used even more if large retailers did not apply protocols that forbid them (especially for seabass), demonstrates that initial worry can be defused when prices are competitive.

If feed price and FCR are the first elements considered by most of the farmers, other factors are more related to the individual characteristics of the farm structures and the business models. Depending on these elements, the effects on organosomatic indices, fat deposition, fillet yield and meat texture, the effects on the quantity and quality of feces, and the variability of performance under different environmental conditions are key for adoption. Finally, the role of large retailers is pivotal, since they should accept insect meal inside the protocols for their own private labels.

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ENDNOTES

[1] The following insect species fulfill the safety conditions for feed use: black soldier fly, *Hermetia illucens*; common housefly, *Musca domestica*; yellow mealworm, *Tenebrio molitor*; lesser mealworm, *Alphitobius diaperinus*; house cricket, *Acheta domesticus*; banded cricket, *Gryllodes sigillatus*; and field cricket, *Gryllus assimilis*.

[2] Fishmeal percentage normally ranges between 10 and 30%.

[3] One of the insect meal producers that have been contacted affirmed that, from their experiments with trout, feeds using 8% of fishmeal and 8% of insect meals (50% of replacement) had a 10% improvement in the FCR. See Arru, Furesi, Gasco, Madau, and Pulina (2019) for a simulation of cost changes in case of differences in the FCR.

[4] Information collected with interviews with feed producers.

[5] Fishmeal, Peru fish meal/pellets 65% protein, CIF (IndexMundi, 2019).

[6] Soybean meal (any origin), Argentine 45/46% extraction, CIF Rotterdam (IndexMundi, 2019).

[7] Often, farmers were not able (did not want) to fill the entire table; thus, more time was dedicated to discussing Questions 3–9.

REFERENCES

Ankamah-Yeboah, I., Jacobsen, J. B., & Olsen, S. B. (2018). Innovating out of the fishmeal trap. *British Food Journal*, *120*(10), 2395–2410. https://doi.org/10.1108/bfj-11-2017-0604

Arru, B., Furesi, R., Gasco, L., Madau, F. A., & Pulina, P. (2019). The introduction of insect meal into fish diet: The first economic analysis on European sea bass farming. *Sustainability (Switzerland)*, *11*(6), 1697. https://doi.org/10.3390/su11061697

Assalzoo. (2018). *Annuario, 2018*.

Borgogno, M., Dinnella, C., Iaconisi, V., Fusi, R., Scarpaleggia, C., Schiavone, A., … Parisi, G. (2017). Inclusion of *Hermetia illucens* larvae meal on rainbow trout (*Oncorhynchus mykiss*) feed: Effect on sensory profile according to static and dynamic evaluations. *Journal of the Science of Food and Agriculture*, *97*(10), 3402–3411. https://doi.org/10.1002/jsfa.8191

Borrello, M., Lombardi, A., Pascucci, S., & Cembalo, L. (2016). The seven challenges for transitioning into a bio-based circular economy in the agri-food sector. *Recent Patents on Food, Nutrition and Agriculture*, *8*, 39–47.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Byrne, J. (2018). Norwegian salmon producer trials Skretting's insect based salmon feed. Online resource: https://www.feednavigator.com/Article/2018/10/25/Norwegian-salmon-producer-trials-Skretting-s-insect-based-salmon-feed

Collins, C. M., Vaskou, P., & Kountouris, Y. (2019). Insect food products in the Western world: Assessing the potential of a new 'green' market. *Annals of the Entomological Society of America*, *112*, 518–528.

Diener, S., Solano, N. M. S., Gutiérrez, F. R., Zurbrügg, C., & Tockner, K. (2011). Biological treatment of municipal organic waste using black soldier fly larvae. *Waste and Biomass Valorization*, *2*, 357–363.

Diener, S., Zurbrügg, C., & Tockner, K. (2009). Conversion of organic material by black soldier fly larvae: Establishing optimal feeding rates. *Waste Management and Research*, *27*, 603–610.

Eumofa. (2019). Eumofa Database. https://www.eumofa.eu/

Gasco, L., Belforti, M., Rotolo, L., Lussiana, C., Parisi, G., Terova, G., et al. (2014). Mealworm (*Tenebrio molitor*) as a potential ingredient inpractical diets for rainbow trout (*Oncorhynchus mykiss*). In Abstract book conference "Insects to feed the world", The Netherlands, 14–17 May (p. 78).

Gasco, L., Gai, F., Piccolo, G., Rotolo, L., Lussiana, C., Molla, P., & Chatzifotis, S. (2014). Substitution of fish meal by *Tenebrio molitor* meal in the diet of Dicentrarchuslabrax juveniles. In Abstract book conference "Insects to feed the world", The Netherlands, 14–17 May (p. 80).

Gasco, L., Henry, M., Piccolo, G., Marono, S., Gai, F., Renna, M., … Chatzifotis, S. (2016). *Tenebrio molitor* meal in diets for European sea bass (*Dicentrarchus labrax* L.) juveniles: Growth performance, whole body composition and in vivo apparent digestibility. *Animal Feed Science and Technology*, *220*, 34–45. https://doi.org/10.1016/j.anifeedsci.2016.07.003

Govorushko, S. (2019). Global status of insects as food and feed source: A review. *Trends in Food Science and Technology*, *91*, 436–445.

Henry, M., Gasco, L., Piccolo, G., & Fountoulaki, E. (2015). Review on the use of insects in the diet of farmed fish: Past and future. *Animal Feed Science and Technology*, *203*, 1), 1–1), 22. https://doi.org/10.1016/j.anifeedsci.2015.03.001

Iaconisi, V., Secci, G., Sabatino, G., Piccolo, G., Gasco, L., Papini, A. M., & Parisi, G. (2019). Effect of mealworm (*Tenebrio molitor* L.) larvae meal on amino acid composition of gilthead sea bream (*Sparus aurata* L.) and rainbow trout (*Oncorhynchus mykiss* W.) fillets. *Aquaculture*, *513*(August), 734403. https://doi.org/10.1016/j.aquaculture.2019.734403

IndexMundi. (2019). Commodity Prices. https://www.indexmundi.com/commodities/?commodity=fish-meal

IPIFF. (2018). *The European insect sector today: challenges, opportunities and regulatory landscape*. https://ipiff.org/ipiff-vision-paper/

Ismea. (2009). *Acquacoltura*. Rome: *Report economico e finanziario*.

Le Féon, S., Thévenot, A., Maillard, F., Macombe, C., Forteau, L., & Aubin, J. (2019). Life cycle assessment of fish fed with insect meal: Case study of mealworm inclusion in trout feed, in France. *Aquaculture*, *500*, 82–91. https://doi.org/10.1016/j.aquaculture.2018.06.051

Madau, F. A., Arru, B., Furesi, R., & Pulina, P. (2020). Insect farming for feed and food production from a circular business model perspective. *Sustainability*, *5*, 418.

Magalhães, R., Sánchez-López, A., Leal, R. S., Martínez-Llorens, S., Oliva-Teles, A., & Peres, H. (2017). Black soldier fly (*Hermetia illucens*) pre-pupae meal as a fish meal replacement in diets for European seabass (*Dicentrarchus labrax*). *Aquaculture*, *476*, 79–85. https://doi.org/10.1016/j.aquaculture.2017.04.021

Makkar, H. P. S., Tran, G., Heuzé, V., & Ankers, P. (2014). State-of-the-art on use of insects as animal feed. *Animal Feed Science and Technology*, *197*, 1–33. https://doi.org/10.1016/j.anifeedsci.2014.07.008

Mancini, S., Sogari, G., Menozzi, D., Nuvoloni, R., Torracca, B., Moruzzo, R., & Paci, G. (2019). Factors predicting the intention of eating an insect-based product. *Foods*, *8*, 270.

Mancuso, T., Baldi, L., & Gasco, L. (2016). An empirical study on consumer acceptance of farmed fish fed on insect meals: The Italian case. *Aquaculture International*, *24*(5), 1,489–1,507. https://doi.org/10.1007/s10499-016-0007-z

Nielsen, R., Guillen, J., & Carvalho, N. (2016). *Economic report of EU aquaculture sector (STECF-16-19)*. https://doi.org/10.2788/189662

Nogales-Mérida, S., Gobbi, P., Józefiak, D., Mazurkiewicz, J., Dudek, K., Rawski, M., … Józefiak, A. (2019). Insect meals in fish nutrition. *Reviews in Aquaculture*, *11*, 1080–1103. https://doi.org/10.1111/raq.12281

OECD-FAO. (2018). OECD/FAO Agricultural Outlook 2018–2027. http://www.fao.org/docrep/i9166e/i9166e_Chapter8_Fish_seafood.pdf

Oonincx, D. G. A. B., & de Boer, I. J. M. (2012). Environmental impact of the production of mealworms as a protein source for humans—A life cycle assessment. *PLoS ONE*, *7*(12), e51145. https://doi.org/10.1371/journal.pone.0051145

Orsi, L., Voege, L. L., Stranieri, S., & Eating edible insects as sustainable food? (2019). Exploring the determinants of consumer acceptance in Germany. *Food Research International*, *125*, 108,573.

Popoff, M., MacLeod, M., & Leschen, W. (2017). Attitudes towards the use of insect-derived materials in Scottish salmon feeds. *Journal of Insects as Food and Feed*, *3*(2), 131–138. https://doi.org/10.3920/JIFF2016.0032

Renna, M., Biasato, I., Brugiapaglia, A., Gai, F., De Marco, M., Schiavone, A., … Gasco, L. (2017). Evaluation of the suitability of a partially defatted black soldier fly (*Hermetia illucens* L.) larvae meal as ingredient for rainbow trout (*Oncorhynchus mykiss* Walbaum) diets. *Journal of Animal Science and Biotechnology*, *8*(1), 1–13. https://doi.org/10.1186/s40104-017-0191-3

Roffeis, M., Wakefield, M. E., Almeida, J., Valada, T. R. A., Devic, E., Kenis, M., … Mathijs, E. (2018). Life cycle cost assessment of insect based feed production in West Africa. *Journal of Cleaner Production*, *199*, 792–806.

Roma, R., Ottomano Palmisano, G., & De Boni, A. (2020). Insects as novel food: A consumer attitude analysis through the dominance-based rough set approach. *Foods*, *9*, 387.

Schlup, Y., & Brunner, T. (2018). Prospects for insects as food in Switzerland: A tobit regression. *Food Quality and Preference*, *64*, 37–46.

Sealey, W. M., Gaylord, T. G., Barrows, F. T., Tomberlin, J. K., McGuire, M. A., Ross, C., & St-Hilaire, S. (2011). Sensory analysis of rainbow trout, *Oncorhynchus mykiss*, fed enriched black soldier Fly Prepupae, *Hermetia illucens* WendyM. *Journal of the World Aquaculture Society*, *42*(1), 34–45. https://doi.org/10.1016/j.aquaculture.2018.03.016

Smetana, S., Palanisamy, M., Mathys, A., & Heinz, V. (2016). Sustainability of insect use for feed and food: Life cycle assessment perspective. *Journal of Cleaner Production*, *137*, 741–751.

St-Hilaire, S., Sheppard, C., Tomberlin, J. K., Irving, S., Newton, L., McGuire, M. A., … Sealey, W. (2007). Fly prepupae as a feedstuff forrainbow trout, *Oncorhynchus mykiss*. *Journal of the World Aquaculture Society*, *38*, 59–67.

Tran, G., Heuzé, V., & Makkar, H. P. S. (2015). Insects in fish diets. *Animal Frontiers*, *5*(2), 37–44.

van Huis, A. (2012). Potential of insects as food and feed in assuring food security. *Annual Review of Entomology*, *58*(1), 563–583. https://doi.org/10.1146/annurev-ento-120811-153704

World Bank. (2013). *Fish to 2030: Prospects for fisheries and aquaculture*. Washington DC: World Bank.

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APPENDIX

Questionnaires

A. **Questionnaire for insect meal producers (sent by email)**

1. Which insect species are you currently rearing to produce meals for aquaculture?
2. Which rearing substrate are you currently using? (please, if you can, provide us some approximate shares if you use different products: e.g., 40% fruit and vegetables, 60% cereals)
    a. Coproducts from agrifood industries (please specify):
    b. Former foodstuff such as vegetal products, dairy, and eggs (please specify):
    c. Commercial feed:
    d. Fruit and vegetables and their derived products (please specify):
    e. Cereal raw materials (please specify):
    f. Other (please specify):
3. How much substrate (kg of dry matter) is needed to produce 1 kg of insect meal?
4. How much insect meal (for aquaculture feed) do you produce per year?
5. What is the protein content (%) of your insect meal (for aquaculture feed)?
6. How much insect meal (for aquaculture feed) do you think you will be able to produce in 2030 (tons, or % increase)?
7. Which is the current price of your insect meal for an enterprise that wants to buy it to produce feeds for fishes? (€/kg)
8. In your opinion, which will be the price of your insect meal in 2030 (€/kg, or % decrease)?
9. Please explain in which way do you think costs can be decreased.
10. Please explain which are the main problems that you must solve to meet the expectations of feed producers (for aquaculture feeds).

B. **Questionnaire for fish feed producers (face-to-face semi-structured interviews)**

1. Please explain us which is the origin of the different raw materials you use and who are your providers.
2. Which is the cost of the different raw materials and their protein content?
3. Which contractual relationships and agreements your company has with fish farmers?
4. Which reasons may have farmers to choose different feeding products (e.g., products with higher/lower fishmeal content, higher/lower FCR)?
5. Please help us to fill the following table for each of the products that your company sells for trout/seabass farming.

Name of the product	Protein content	Fat content	Fishmeal content	LAP	Price	FCR	Who buys this product?
XXXXXXXXX							

C. **Questionnaire for fish farmers (face-to-face semi-structured interviews)**

1. Please illustrate the main characteristics of your plant/plants (i.e., origin and characteristics of water, oxygenation techniques, waste treatment, basin material, etc.).
2. Please help us to fill the following table listing the different feeds that you use during the life cycle of trout/seabass.[7]

Farming stage (fish weight)	Duration	Feed used	Feed price	Feed used/fish weight ratio	FCR measured	Fish density
I.						

3. Initial weight of the fry:
4. Duration of the cycle:
5. Final weight of fish:
6. Total FCR:
7. Average price of feed products:
8. Fish price:
9. Cost of feed/price of fish ratio:
10. Cost of feed/other operating costs ratio:
11. Kind of buyers:
12. Which are the main problems related with fish feeding?
13. Which are the elements/drivers/objectives that you consider when you choose a specific feeding product?
14. How did you take your current decision? Who suggested you in your decision? Do you make trials on feeds? Have you frequently changed feed in the latest years?
15. Is the raw material used for feeds relevant? Why? What is your opinion on feeds where fishmeal is replaced with vegetable proteins/LAPs/insect meal? Could this element affect the preferences of your customers?