THE DEVELOPMENT OF A FORMED BAIT SOLUTION FOR THE IRISH WHELK FISHERY

ORIGINAL PROJECT TITLE: NEW BAIT FOR BROWN CRAB

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Context

Inshore pot fishing in Ireland is an important sector with c. 22,969MT of shellfish landed in 2016 (e.g. crab, whelk, lobster, prawns, shrimp), worth €57,361,570. A large quantity of bait is used annually. Typically, between 200-400grms of bait is used per pot, which will last up to 4 days in a soak cycle at sea. 200grms of bait will yield a catch of c.1kg of target raw material (Seafish report). This suggests an estimated 3,000MT of bait is used annually. In the Brown Crab (*Cancer pagurus*) fishery, small pelagic spp. (e.g. horse mackerel, mackerel) are traditionally used but costs have increased significantly (>€800 per MT), due to direct competition from global human and non-human consumption markets. These high costs are presenting viability challenges for crab and whelk fishers. Within the whelk fisheries (*Buccinum undatum*), dogfish and poor quality or damaged Brown Crab are used as bait raw material. Fish frames/offal is also used, however consistent availability and quality of source material is problematic.

In summary, the main issues that are presenting for inshore pot fishers regarding bait are the increasing costs and quality of the raw material. Furthermore, of increasing importance, particularly in the whelk fisheries is the unsustainable practice of using Brown Crab as a source of bait raw material rather than the raw material being returned alive to the sea. This is putting increasing pressure on brown crab fisheries and makes it a practice that fishers want resolved for the benefit of both whelk and brown crab fisheries.

A variety of formed bait have been developed for certain commercial pot fisheries in recent decades. The bait is typically produced using fish by-products/oils and a binder. To date, there has been limited uptake of these baits largely due to cost and performance issues. Although formed baits have been used sporadically in Irish pot fisheries, to date none have gained commercial traction. It is suggested that this is largely due to the complexity of developing a good quality consistent formed bait product.

Aims of study

The original aim of this study was to develop a formed bait for the Ireland's brown crab fishery. However, from engagement with a wide variety of crab and whelk fishers (Appendix I) it became clear that the priority focus was the development of formed bait solution for the Ireland's whelk fisheries. Therefore, the scope of the study focused on the provision of a formed bait solution for Irish whelk fisheries. The following were the specific objectives of this study:

1. Engagement with stakeholders to determine a profile of bait and preferred bait solutions.
2. Production of a literature review detailing the current state of the art of regarding commercial formed bait for whelk and crab fisheries.
3. The production and trialling of formed baits.

1. Engagement with stakeholders

Irish Fishery Improvement Projects or FIPs have established in recent years. FIPs are an industry-led approach to improving sustainability of specific fisheries in an ever more demanding marketplace. They are based on co-operation between all sectors in the fishery chain, from catching to processing to retail in collaboration with NGO's who wish to see fishing continue while progress towards sustainability is made. Stakeholders within FIPs were the main drivers seeking an affordable formed bait solution for Irish whelk fisheries.

A questionnaire was circulated through the FIPs to inshore fishers to gain feedback on the use of bait, the challenges and types of solutions sought (Appendix I). The main feedback generated from the questionnaires is summarised below:

Types of species fished:

The range of species fished from respondent's ranges from Brown Crab, Lobster, Whelk, Shrimp and Velvet Crab, with the larger vivier boats just targeting Brown Crab and the smaller boats targeting all species. The types of bait used for each species are listed in table

Target species	Bait used
Brown Crab	Frozen herring/mackerel, Dogfish, whiting, herring, scad, Whole round herring, mackerel, Horse Mackerel, Mackerel frames and Whitefish frames
Whelk	Crab/dogfish, Dogfish + Brown Crab, Spider crab
Lobster	Frozen herring/mackerel, Salted Mackerel, Salted whitefish offal, Whiting, herring
Shrimp	Frozen blue whiting

Average trip length:

The larger vivier boats would spend on average 6-7 days at sea per trip. The small boats targeting all species would be at sea for 1 day per trip. Depending on the size of the boat and length of trip, the vivier boats would use 2,500 / 3,000 kg of bait per 7-day trip and the day boats between 20Kg and 200 kg per trip.

Preferred storage method for existing bait:

The preferred storage method on the vivier boats is frozen at the moment as the boats are at sea for 1 week at a time and they are using a mix of Whole Round Herring, mackerel, Horse Mackerel,

Mackerel frames and Whitefish frames. The smaller boats have bait that is collected daily from processor, either frozen or salted.

Preferred storage method for new bait:

The preferred method for storage would be a dry bait that can be stored in ambient temperatures, possibly in clean, easily handled containers with lids that can be kept anywhere and not be messy or smelly. Following this is chilled storage, then frozen.

Is there a problem accessing bait:

The majority of fishermen have stated that there is a problem accessing bait. For the larger boats the problem lies in there is reasonable supply of pelagic Bait available from October to March but by this time the pelagic fishing is over, leaving suitable pelagic bait scarce from April to October. The cost of bait is also an issue with Horse Mackerel from €750 to €900 per tonne, Herring €550 / €650 and Mackerel €700 / €950 per tonne (small and damaged). With the smaller boats, sometimes the quality is not good (you do not know until bait thaws out if its fresh) and if bait quality is poor, you will see a decrease in catch.

What they like about the competing bait products on the market:

None of the fishermen questioned use a formed bait. What they dislike about the competing bait products on the market is high prices. In addition, the pelagic bait is not as available as in the past, and the cost is very high. White fish frames which are also used are approx. €350 per ton, but not as good a bait as the pelagic.

Things that would help them decide to change to a new type of bait.

A higher catch yield per pot at a lower cost, with a proven track record of its quality and ability to catch fish, and a competitive price for the bait. In addition, hearing that it had been tried and tested by reliable fishermen and that it was already established and in regular use. Also, having a long lasting scent under water is key.

Is formed bait the most appropriate solution?

All questionnaires came back indicating that this is the right direction, especially for whelk fishing as they need to get away from using crab as whelk bait. It is very important to eliminate the landing of poor quality crab for use as bait. This crab should be returned alive to the water to increase the sustainability of the crab fishery itself. In addition, the availability of pelagic bait is getting lower every year, with lower quotas for Irish boats, and what is available, has become very costly. On a weekly trip on a Vivier boat, the cost of bait is at times higher than the cost of diesel for the trip.

Usage of formed bait and opinions on the formed bait

More than half the fishermen questioned had used formed bait in the past. Of those that had it was aimed at lobster fishery. It was successful for lobster but crab and velvet crab catches dropped by 80%. They used only small quantities on trial, not enough to make a decision. Of those that didn't use formed bait in the past, it was because they don't know anything about using it and they catch most of their own bait and obtain the rest from a local processor.

How interested are they in using a new formed bait?

Most would consider using a new formed bait and they stated an interest from somewhat interested to extremely interested.

Reasons behind their need for a new formed bait.

Several reasons were expressed, from it becoming increasingly difficult to source bait to existing bait becoming too expensive. They would like the convenience of handling, storage and use of a formed bait and would like the performance of a targeted bait. They also want a cost effective bait that will fish well in the pots, last a reasonable time and, of course, catch yield is very important

The price would they expect to pay for a new formed bait;

The price point the fishermen have suggested is between €0.50 and €1 per Kg for the bait. However, they would pay more for a bait that performed better.

The problem they see formed bait solving that is not available with other types of bait.

A formed bait targeted at the whelk fishery, if successful, would take huge pressure off Brown Crab stocks, as there would no longer be any excuse for landing other than good quality crab. It would be very helpful to the Brown Crab FIP. In addition, it would mean availability of bait at any given time: in theory, one could buy 3-4 months' supply and never have to worry about sourcing. Storage is an issue and a formed bait in 20-25 lt tubs with lids would be clean to keep in a cool shed or below decks, smell free. Possibly lower cost also.

2. A literature review of formed bait for Whelk (*Buccinum undatum*) and Edible Crab (*Cancer pagurus*)

Introduction

The cost and availability of bait used in shellfish fisheries is a significant burden for fishermen, with bait costs accounting for up to 11% of their gross costs [1]; at the same time, satisfactory quality bait has become increasingly difficult to obtain. According to the Food and Agriculture Organization of the United Nations (FAO), the use of certain fish products currently used as baits (e.g. mackerel and herring) should only be used for human consumption. Some fisheries have moved towards the use of by-products as replacement baits for the conventional mackerel and herring.

The primary goal of this report is to describe the current use of bait in the crab and whelk fisheries in Ireland and Norway and to present a review of previous work within development of artificial bait in these two fisheries.

Edible crab

The edible crab or brown crab (*Cancer pagurus*), is a species found in the North Sea, North Atlantic and the Mediterranean Sea. The total catch reported for this species to FAO for 2016 was 53,728t. The countries with the largest catches were UK, Ireland and France. Brown crab is the most profitable pot fishing species in Ireland with a catch of 7,285 tons [2]. Brown crab is landed in all major and many smaller ports around the Irish coast. Although traditionally an inshore fishery, a significant proportion of landings are from the offshore fleet, which predominately fish off the northwest coast of Ireland.

In the early 1990s the Norwegian edible crab fishery struggled with low profitability, and the annual catch was approximately 1,300 tons. To facilitate the development from a subsidized industry towards a modern profitable industry, a national development program was established and in the period from 1990 to 2015, the annual catch increased from 1,300 tons to 4,700 tons (FAO 2018). In Norway, the edible crab fishery is seasonal and takes place between August and November.

The common whelk

The common whelk (*Buccinum undatum*) is a scavenging and carnivorous gastropod living on the seabed at depths between 10 and 120 m. Its distribution is patchy and almost all fishery is located within 10 km from shore. In Ireland, whelk is mostly fished by small fishing vessels using traditional pots. The commercial fishery of whelk in Ireland had increased in the early 1990s due to an increased demand in the Asian market with the highest landings occurring in 2003. Subsequently, landings have

fluctuated, and the total catch reported to FAO in 2016 was 2,621 tons. The history of whelk fishing in Norway is similar to that of Ireland but it started only a century ago. From being almost nonexistent, there are now tens of commercial actors. The landing of whelk has increased from 16 tons in 2010 to over 300 tons in 2016. The whelk fishery's increasing popularity is likely to result in the whelk being subject to regulations in the form of quotas in coming years. This is managed by the Norwegian Directorate of Fisheries.

Fishery and current bait usage

Both crabs and whelk are caught using traps, in addition, one company in Norway catches whelk by diving. Several different models of traps are used in the crab fishery, from homemade traditional wooden traps, to commercially produced traps made from recycled polyethylene (e.g. Polymoon Ltd.). Some trap models are equipped with a compartment for the bait, but most are not. The most commonly used traps contain two entrances [3], as seen in Figure 1.

Figure 1 Most commonly used Brown crab trap with two entrances used in Norway.

Norwegian whelk fishermen use commercial traps as well as homemade pots made out of plastic cans (figure 2b). Most pots are made out of plastic with an opening on the top, covered with a net, and a weight in the bottom (Figure 2 a, b and c). The bait is placed at the bottom of the pot in a bait net.

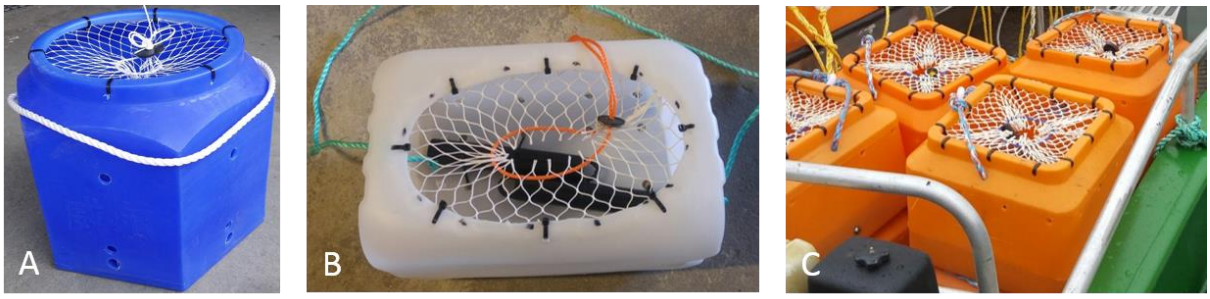

Figure 2 some of the whelk pots used in Norway. A) a commercial whelk pot from *Sealine products,* B) homemade pot, C) squared pot.

Currently, the type of bait used in whelk and crab fishing is dependent on the area and availability of suitable products. In addition, the traditional bait types that have been used for decades also influence bait choice. The most commonly used bait for catching brown crab is fish frames and pelagic fish in both Ireland and Norway; mackerel being the most frequently used fish in Ireland and herring in Norway. A large quantity of bait is used annually, typically between 200–400 grams of bait per pot. Typically, 200 grams of bait will yield a catch of 1 kg of target raw material. Therefore, in Ireland an estimated 3,000 tones bait is used annually (pers. com, Michael Cannon, BIM). Estimation for bait usage in Norway is missing.

For catching whelk, different types of crabs are widely used. Horseshoe crab are popular in North America and brown crab is used in Ireland and UK [4, 5]. In Norway, small fish (herring and saithe) or fish frames (cod and saithe) is the most commonly used bait in both whelk and the brown crab fishery, mainly due to availability. Furthermore, in research trials and studies on whelks in Norway, different types of clam have been used with good results.

Artificial baits

Despite several attempts to develop commercial artificial baits, there are to our knowledge no artificial baits for edible crab or whelk which are commercially available in Norway or Ireland. For other crustaceans, such as spiny lobsters, lobsters, snow crab and crayfish, several types of artificial baits have been developed [6-8]. However, none of them have been commercially successful. Previous research on artificial bait is listed in Table 1. Although factors such as price and logistical problems may contribute to the lack of success for the artificial baits in commercial fisheries, the lower effectiveness is the most obvious reason. The reason for the low effectiveness seems to be related to the processing. It seems that the more one processes the raw material, e.g. dries or cooks, the more of the attractive components are lost or altered. Finding a working binder also seems to be a problem. Without an effective binder, the bait disintegrates too fast. If the binder is too effective, too little attractant is released or the release is too slow. Some of the artificial baits developed are synthetic with industrially made attractants picked out based on chemosensory tests performed on whelks and crabs. However, the components tested and shown to trigger food search behavior are not sufficient triggers to make the crab or the whelk pursue the smell. It seems the chemosensory cues involved in triggering food search in crabs and whelks are more complicated than one would conclude based on research done on these animals' nervous systems.

Sensory organs and foraging behavior

Crabs and gastropods have a preliminary reliance on odor-based navigation when foraging. For the crab or whelk to move towards and into a baited pot a set of different behavioral responses need to

be triggered. The forage behavior can roughly be divided into three phases: detection of a chemical cue, interest in the scent and finally action. The chemosensory systems involved in the process can be divided into two categories: olfactory and gustatory, both playing an equally important role in the animals' decision-making as to whether a chemical cue is worth pursuing. There have been attempts to define and find molecules in extracts from known good bait sources that elicit foraging behavior in different decapod and whelk species, but the results are somewhat divergent. They are summarized in the following sections.

Crustaceans

Chemosensory, sensory, hairs containing chemoreceptor cells, are located on much of the body surface of aquatic crustaceans, including both pairs of antennae (antennules and antennae), the mouthparts, and the claws and walking legs [9]. The antennules, containing aesthetasc sensilla, are usually referred to as olfactory (smell) organs, whereas antennae, walking legs, and mouthparts are usually referred to as gustatory (taste) organs [10]. Crustaceans use antennule chemoreception to identify attractive food and both fish and crustaceans use their olfactory and gustatory systems to detect amino acids, amines, and nucleotides, among many other compounds [11, 12]. The majority of studies on chemo-attraction in crustaceans have shown that low molecular weight (LMW; <1000 Daltons) compounds such as AA, amines, nucleotides and organic acids are the most attractive individual compounds [13-15]. The attractiveness of compounds appears to be species-specific as for fish [16]. It is generally assumed that LMW compounds are the most effective attractants because of their rapid diffusion rate [13, 15]. However, this conclusion may be premature and species-specific, as only few studies have tested both LMW and high molecular weight. Zimmer-Faust et al. (1984) showed that California spiny lobster (*Panulirus interruptus*) was stimulated by the HMW fraction (>1000 Dalton) of abalone extract, but not the LMW fraction (<1000 Dalton). The ghost crab (*Ocypode quadrata*) and American lobster (*Homarus americanus*) are two examples of crustaceans that only respond to the LMW fraction of prey extracts [14, 15, 17].

A behavioral study on California spiny lobster (*Panulirus interruptus*) showed that tests using single compounds could not reliably predicate the attractiveness of mixtures. The authors tested the effects of over 30 individual compounds from abalone muscle on the lobster and found that 10 single compounds (glycine, alanine, serine, methionine, isoleucine, leucine, lysine and glutamine acid) induced feeding behavior. They also tested the effect of mixing glycine with urea, ammonium and taurine, amino acids thought to work as attractants. The results showed less attractiveness of mixture than single class mixtures. In contrast, a mixture of the organic acids succinic and oxalic acid, with glycine, alanine and serine was more attractive than a single class mixture [18]

Whelk

The osphradium located in the pallial cavity which is connected to the incurrent siphon is considered the primary chemosensory organ of the whelk [19]. However, the prosobranchs also use the rhinophores in determining the direction of an odor plume [20]. Whelks are also shown to have an ability to determine the size of possible prey when approaching a feeding sea star [21]. The gustatory organ is also fine-tuned, and the whelk is a highly selective feeder. In feeding trials with Channel whelk (*Busycotypus canaliculatus*) , the whelk only consumed the animal component of a pellet [22] and in a field study on scavenging of animals killed by beam trawling, the whelk were observed to feed on the most energy-rich carrion first [23]. Laboratory studies have also been done on the chemoreception of whelks and the results obtained are somewhat like those for decapods. Wakefield et al. (2007) made a study where they made extracts from horseshoe crab eggs and separated this extract into two fractions: one containing molecules over 3 kDa and the other containing molecules under 3 kDa. The whelk did not react to the extract fractions when tested separately but recombining the fractions gave the same response as untreated extract [24]. Furthermore, they were not able to induce foraging behavior with single amino acids. To trigger the nervous system for food search, a combination of amino acids was required.

Examples of artificial baits previously trialed with promising results

Nofima bait

Four formulated baits for the edible crab were developed using fish skin (50 %) as a binder. Fish skin gelatin strengthened by the enzyme transglutaminase worked as a binder in the baits. Attractants were then added to the baits. A meal mixture of shrimp, kelp and fish was added to one bait (bait A) as attractant. In the second bait (Bait B), protein concentrate from cod (*Gadus morhua*) by-product was added in addition to the meal mixture in bait A. Blue mussels (*Mytilus edulis*) and cod roe were used as attractants in bait C and D respectively. During three field studies, the performance of the formulated baits was compared with that of the most commonly used natural bait, chopped untreated saithe (*Pollachius virens*). The catch in traps baited with Nofima bait C and D resulted in significantly higher catch both compared to traps baited with bait A and to control baits [3]. The same baits were also tested by a commercial whelk fisherman in Norway with promising results. Scientific data from this test is missing.

OrganoBait

OrganoBait is developed by Kepley Bio Systems in USA. The bait is synthetic and claims to be of sustainable material with calcium sulfate as gelling agent and industrially manufactured amino acids. According to the bait description on the OrganoBait homepage, “The bait mimics the attractant

properties of “forage” fish and is designed for use as crustacean fishing bait” [25]. The bait is currently not commercially available.

University of Delaware bait for whelk

A team of researchers at the University of Delaware, led by Nancy Targett, has developed artificial bait for whelk made from alginates derived from brown seaweeds and kelp, a small amount of coarsely ground horseshoe crab, green shore crab (*Carcinus maenas*) and food-grade chemicals including baking soda and citric acid. When mixed, these ingredients form a quick-set gelatin that remains stable for up to four days [26] The bait can be ordered from LaMonica Fine foods or the recipe can be downloaded from the Delaware University Grant website.

Artificial bait components

In order to develop a commercially interesting artificial bait, the following criteria need to be met:

I) The alternative bait must have an equal or lower price (for the same amount of the target species caught) as traditional baits;

II) A defensible alternative to the present raw material source should be used.

III) The new bait must attract the target species at least as well as traditional baits.

Visibility in seawater is often limited. Therefore, odors released by prey items are important for food search behaviors. Nearly all crab and fish use olfaction for prey detection at greater distances (Meyers 1997, Løkkeborg, Siikavuopio et al. 2014). There are many challenges to the development of an artificial bait to replace traditional baits. The artificial baits need to meet biological and mechanical standards. In addition, they must be made from sustainable resources (Løkkeborg, Siikavuopio et al. 2014). Importantly, the bait needs to release an odor that promotes food-searching behavior in the target species. The bait must release these attractants over a sufficient period, i.e. over several days in edible crab fisheries [3].

There are two main components to an artificial bait:

1. Attractants
2. Binders (Carrier)

Both must meet important requirements in order to form an efficient bait. Whether natural or synthetic, the attractants must include the stimulatory compounds that initiate food-search behavior in the target species. The purpose of the binder is to ensure that attractants are released over a long period of time. Previously, the release rate of attractants from natural baits has been shown to

decrease very rapidly [27]. It is likely that baits with prolonged release rates would increase catch rates. Since the binder (gelling agent) normally does not add sufficient physical strength to the bait, a reinforcement is needed to ensure that bait is not lost while setting the pots or eaten by benthic scavengers arriving before the target species.

Bait quantity is also shown to affect catch rate in some studies [8, 16], and not in others [28]. Yet other studies indicate a threshold over which the quantity of bait does not affect the catch rate. In the study of Zimmerfaust and Case (1983), traps baited with abalone muscle in the weight range of 46–372 g had similar catch of California spiny lobster, whereas baits in the range 18–3 g yielded progressively lower catch rates. Also for artificial baits, lab studies have shown that different concentrations of attractant evoke different behavioral responses [8]. The response of the animal increased moderately with order of magnitude increase in concentration of attractant, typically a two- or three-fold increase in response to a 100-fold increase in attractant concentration [12].

Sources of raw material

Ideally, artificial bait should be based on low-cost products and the source of raw materials should not conflict with other economic interests. Therefore, a future bait should ideally be based on by-products from, e.g. fish processing industry, aquaculture or animal husbandry.

Currently one source of bait used is frames derived from processing of farmed and wild caught fish. The usage of waste products from the fish processing industry is beneficial for the fish farmers as well as for the industry and could be a good alternative to the forage fish used as bait today. However, the usage of untreated waste products from the fish industry can cause the spread of pathogens, especially in fish farming areas [29]. Therefore, it is crucial that potential pathogens in raw material used for bait production are eliminated.

The blue mussel industry produces large amounts of mussels that do not fulfil market requirements (small size, fouling, cracking etc.). These form a potential source, together with waste from the fish processing industry, of low cost ingredients in artificial baits.

Attracting agent

In order to act as a feeding attractant to scavengers and predators, the molecular fluxes from the bait must simulate the natural amino acid release from prey and carrion (Zimmer et al., 1999). Selection of attractant(s) should therefore be done with care and with the target species in mind. Mussels from the genus Mytilus, are commonly used as bait [30] and furthermore, brown crab as well as whelk are known to consume a variety of molluscan prey in the wild, among those blue mussel (*Mytilus edulis*) [21, 31]. Carr et al. (1996), attributed the popularity of molluscs as bait and

feed additives to their high concentrations of what the author defines as “most frequently cited stimulant” (MFCS). In extracts from blue mussel betaine, taurine, alanine and glycine were the dominant components, where both betaine, glycine and alanine are represented among the MFCS [32]. In the study of Carr et al. (1996), the list of MFCS was derived from studies on 35 species of fish, and to our knowledge no similar studies have been carried out for crustaceans. However, marine invertebrates have high sensitivity for the amino acids serine, alanine, histidine and glycine (Ache 1987), and it is therefore plausible that blue mussels could function well as attractant in bait for edible crab. Since the diet of the whelk is somewhat similar to that of the brown crab one could adopt the hypothesis for whelk as well.

Some studies have shown that a combination of bait types gives a bigger catch. In a study by Fahy et al., a combination of dogfish and brown crab gave a better whelk catch than brown crab alone. However, no difference in catch between pots baited with fish only or fish in combination with scallop (*Chlamys islandica*) was registered in a study done in northern Norway [33]. This can indicate that it is the nutrient composition and the energy content that determines the attractiveness of a prey, as Evan et al. (1993) proposed in their study [23].

Binder

The type of matrix should also be chosen carefully. The attractant carrying agent should pose no hazard to the environment. The matrix should be biodegradable or of natural material, also digestible in case of ingestion by scavengers or target species. The type of binder influences the leaching of attractant, [8, 34], and therefore the efficiency of the bait. In addition, the biochemical composition of different attractants affects the binder and leaching capacity. High strength binders such as gelatin, agar and some synthetic polymers cause a slow release rate of attractants (Løkkeborg, Siikavuopio et al. 2014).

Summary and proposal for an artificial bait for whelk and Brown crab

The sensitivity to a bait is not only species-dependent but also varies with season and food availability in the area. In addition, food preference changes due to changing nutrient demands depending on sexual maturity, spawning and molting. Research show that there are different cues inducing olfactory responses and interest in a scent and actual foraging behavior, which leads to the target species entering a pot. The chemical cues leading to foraging behavior are proven very complex and as of today there is not sufficient information on which compounds and in what amounts they are needed in order to elicit the entrapping food search behavior in whelk or brown crab.

The natural diet of whelk consists of a variety of invertebrates that it preys upon, including different type of mussels. The whelk is also an opportunistic carrion feeder. However, whelks show preferences for the most energy- and nutrient-rich carrion. In a study, Hughes et al. (1996) noted that the whelk consumed the crab carrion first. Bait studies on whelk done by Fahy (2001) have shown that a combination of baits can increase attractiveness and when testing different extracts from horseshoe crab, Ferrari & Targett (2003) found that a combination of different molecules is needed in order to activate food search behavior in the dog whelk.

Our recommendation is that artificial bait should be based on raw materials that exit carrion in its whole complexity. This based on the research done on chemoreception of these two species, their foraging behavior as well as the efficacy of the baits used today. An artificial bait based on a handful of industrially manufactured amino acids may be a possibility in the future when the food search triggering amino acids, amines, nucleotides and organic acids have been defined for each species.

Considering the availability of raw material accessible in Ireland today, blue mussels and whitefish and fish discards could constitute as sensible attractant in an artificial bait. As previously mentioned, the binder effects the effectiveness of the bait and even though a dry bait is the ideal, a moist gelatine based might work better.

Bait				
Carrier/Matrix	Attractant	Target species	Results	Ref.
34 % wheat starch and other ingredients	30% mackerel and or squid waste Garlic Brown sugar	Sand Crab	Poorer fishing than control.	[35]
45-50% fish skin 19-50% saithe	Fish, kelp and shrimp meal Bait 1 + PC Blue mussels Cod roe	Brown Crab Whelk	Bait C and D worked as well as or better than the control.	[3]
Gelatin	Fish products Saccharide Essential oil Dried grain Soy meal Poultry by products	Cambarid crayfish	Only bait with high content of fish products fishes as well as or better than the control.	[36]
Crude fiber (Purina®)	Protein (Purina) Cut gizzard chad	Cambarid crayfish	Temperature/season dependent. In summer Purina bait. During winter cut gizzard.	[37]
Calcium sulfate «OrganoBait»	Not stated. Small molecular amino acids?	Stone crab, Blue Crab Spiny Lobster American lobster	As good as or better.	[25]

Minced fish	Sugar	Swimming crab	Sugar decreases by catch, possibly negative effect on catch rate of crabs	[38]
Minced fish	Fish with minced brown crab	Brown crab	Bait containing crab significantly reduces catches	[39]
Cyclodextrin Resin	“Inducement agent”	crustacean	Poorer fishing than control (fish)	[40]
Not stated	Poultry	Blue Crab	As good as	[41]
«Celtic bait»	Brown crab and dogfish	Whelk	Not as good as	Fahy (2001)
«Delaware» Citric acid, Baking soda, alginate	Green shore crab, Horseshoe crab	Whelk Eel	As well as	[26]

3. The production and trialling of formed baits.

Introduction

Ideally, alternative baits should be based on low-cost surplus products, and allow for longer fishing times than natural bait. By- products from marine industry meet these criteria. Baits from this resource makes fishing more cost efficient, as well as being socially acceptable and environmentally friendly. However, the development of an alternative to traditional bait is challenging, as it needs to meet biological, mechanical and technical standards, and it must be made from sustainable sources. In order to be effective, the bait must be based on an odour source that elicits food-searching behaviour in the target species and it must release these attractants over a sufficient period of time. Brown crab has proven to be a some of ultimate bait for catching whelk. With declining stocks and the fact of brown crab being a valuable fishing resource, this imposes great challenges for the whelk fishery. The aim is to develop a substitute for brown crab as bait that is cheap, user friendly and with satisfactory catch rates.

The work for developing a bait has been divided into two separate work fields. Produce the attractant and test the bait in lab and in field.

Attracting agent

Although factors such as price and logistical problems may contribute to the lack of success for the artificial baits in commercial fisheries, the lower effectiveness is the most obvious reason for the absence of artificial baits on the market. In order to facilitate finding the attractants from a selection of potential attractants. Small scale laboratory studies are conducted as well as field tests in Ireland.

Materials and method

Production of attractants

The attractant from blue mussels (*Mytilus edulis*) was processed in Nofima's BioTep Plant in Tromsø to yield a concentrated protein hydrolysate. The BioTep process line is equipped with a crusher to crush frozen blocks of raw blue mussels' material. Crushed frozen material was transported to two parallel hydrolysis vessels by a screw conveyor. Each vessel has a steam jacket, stirrer, temperature control and weight control. The set temperature for reaction was 52°C, reaction time was set to 120 minutes with the enzyme Alcalase 2,4L in a concentration of 1% of wet weight raw material (i.e. 10 kg liquid Alcalase in each reactor). An enzyme reaction temperature of 60°C is well suitable for the enzyme Alcalase 2,4L, while a temperature of 75,3 °C would be preferred lower. After 120 minutes of reaction time, the mixtures in the reactors was heated and kept at 90°C in 10 minutes to inactivate

the enzyme. After hydrolysis the hydrolysed material was drained to a dump tank. The tank is equipped with a sieve and a screw conveyor separating the liquid hydrolysate suspension from the non-solved bigger particles. The liquid hydrolysate is collected in a stirrer equipped vessel and fed continuously to the rest of the process line. The non-solved particles are transported to a shaking board where remaining liquid hydrolysate is collected and transferred back to the feed vessel. Non-solved particles are collected in a container. The liquid hydrolysate was then fed to a tricanter separating the oil and the fine solids (grax) already passed the previously mentioned sieve. To further purify the liquid hydrolysate it is passed from the tricanter through a separator to remove remaining solids and oil. The purified hydrolysate is intermediately accumulated in a vessel before concentrated in an evaporator. The hydrolysate's characteristics and concentrated up to 60% dry weight for conservation. The final concentrate was stored at 4^{o}C. The process line is equipped with several heat exchangers to keep the temperature of the hydrolysate high during the whole processing time. Process and equipment was all food and feed grade quality. The hydrolysate was mixed with the bait matrix (binder) in a concentration of 10 % dry weight of the bait. The production cost of the attractant at Nofima commercial facility was calculated to 4,3 GBP/kg (blue mussel attractant. The production cost of the other attractant used in this experiment was made in lab scale, which is not realistic to calculate the production cost.

The second test production of attractants by enzymatic hydrolysation of brown crab, green shore crab and dogfish was conducted in Lab scale at Nofima in Tromsø. From brown crab clusters (10 kg from 134 individuals) and bodies (10 kg from 136 individuals) were separated. From green shore crab and dogfish 10 kg was homogenized using the entire animal. The samples were added 15L of water, heated to 60*C, added 0.1% alcalase and hydrolysed for 1h. Enzyme deactivation after 1 h at 90*C for 15 min. Samples were centrifuged at 7,000 g for 20 min and water phases were kept for further studies. Samples were evaporated at 70 ^{o}C and maximum achievable vacuum (typically in the range of 80-150 mBar). The hydrolysate was mixed with the bait polymer ingredients prior to polymerization. After polymerization the bait (polymer mixed with hydrolysate) was air dried and subsequently homogenized (broken in smaller pieces). Table1 provides an overview of the amino acid profile of the attractants. The bait matrix (Nofima bait matrix, based on natural polymer) was mixed with a hydrolysate concentration of 10% (dry weight) and 20% polymer. After drying, the bait consisted of 67% polymer and 33% hydrolysate. The progression of attractant leakage (hydrolysate + other components) depends on the size of the bait and the design of the bait box. In our experience the migration can be adjusted to occur for a few hours up to several days.

Tabel 1 Amino acid composition in g/100 gram of sample of bait 1-3. baits made of hydrolysates of shrimps, blue mussel, Brown crab legs, brown crab bodies and whole green crab.

	Shrimps	Blue mussel	Brown Crab		Green crab
Amino acid			**legs**	**bodies**	
Asparagine	2,8	2,1	1,4	1,8	1,5
Glutamine	4,0	2,6	2,7	2,6	2,3
Hydroxyproline			< 10	< 10	< 10
Serine	1,3	0,89	0,58	0,77	0,69
Glycine	2,3	2,0	2	1,4	1,2
Histidine	0,85	0,39	0,37	0,57	0,46
Arginine	2,24	1,3	1,7	1,6	1,1
Threonine	1,2	0,90	0,55	0,82	0,7
Alanine	1,85	1,2	1,1	1	0,97
Proline	1,7	0,79	0,68	0,86	0,99
Tyrosine	0,97	0,43	0,34	0,43	0,62
Valine	1,6	0,90	0,65	1,0	0,86
Methionine	0,84	0,47	0,36	0,48	0,43
Isoleucine	1,4	0,78	0,52	0,88	0,76
Leucine	2,08	1,2	0,93	1,3	1,2
Phenylalanine	1,4	0,61	0,50	0,76	0,73
Lysine	2,2	1,4	1,2	1,5	1,1

Laboratory tests

The laboratory tests were conducted at Tromsø aquaculture research station with whelks caught in the nearby area as by catch in Brown Crab traps and with sea urchin traps baited with herring. The whelks were kept in a tank with flow through water at ambient temperature. Whelks was fed a mixed diet of pollock and herring but kept unfed for 3 days before test trials. The trials were run in July and November 2018 and January 2019 at ambient water temperature ranging from 9 to 5^{o}C.

Test set-up

The preference tests were conducted in a raceway with a laminar flow of 1 L/min. In total 5 whelks are placed down at the bottom end of the track (area D) and the baits are placed at the upper end at point A or B. The whelks could search for the bait for in total of 20 minutes. Only snails that has entered the area C was registered as active and considered. The number of snails in area A, B or C were registered after 10 and 20 minutes. The bait was scored according to the share of active snails it attracted.

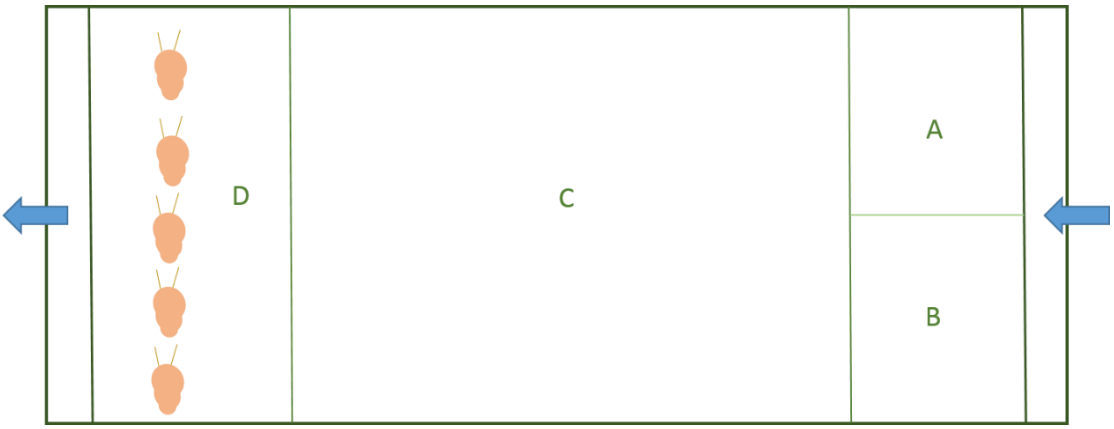

Figure 3 test set up for testing different attractants on common whelk. Blue arrows show the water flow. The snails are placed in area D all facing the same direction. Substances to be tested are placed in the middle of area "a" or "b". After 10 and 20 minutes the NUMBER of whelks in area A, B, and C are counted.

Results

lab-studies

The set up was tested using pieces of pollock as bait placed in either area A or B. The whelks find their way to the bait at an average time of 15 minutes. Therefore, only the count after 20 minutes is considered in the results part. Control tests run with only sea water show that the whelks distributed themselves randomly over the whole test area. The water temperature did not seem to influence the activity level among the whelk but the overall interest for food decreased with lower water temperatures. This was observed during feeding between trial days.

In tests where attractants are tested up against each other, Brown Crab, as expected, has the greatest attracting effect. The combination Blue mussel with added taurine and Brown Crab also induces high activity among the whelks (Table 3). To also be noted is the result for Salmon blood (blood with heparin, defrosted) and Shrimp that both scored relatively high.

Attractants tested	Average score	Whelk activity %	N	Temp °C
Blue mussel +taurine Blue mussel	0,43 0,29	54,3	13	5
Blue Mussel Fish feed pellet	0,39 0,36	55,0	8	8,1
Salmon blood Blue mussel	0,46 0,25	37,8	9	9

Cod head Blue mussel	0,33 0,29	58,0	10	9
Blue mussel +taurine Shrimp	0,18 0,46	51,3	8	5
Brown Crab Blue mussel +taurine	0,66 0,13	62,0	10	5

field-tests

Field test 1 (December 2018)

The field test 1 was conducted in December 2018. The experimental baits were coded with letters D (fish discard) and E (Blue mussel). The pots were baited in intervals of 5 pots with "D" and dog, 5 pots with "E" and dog, next 5 pots bait as normal with crab and dogfish and so on. Pots baited with control bait (Normal bait) had the significant highest catching rate. The artificial bait with mussel had significant highest catch compared with artificial bait made of cod intestines (Bait D)(Fig.2).

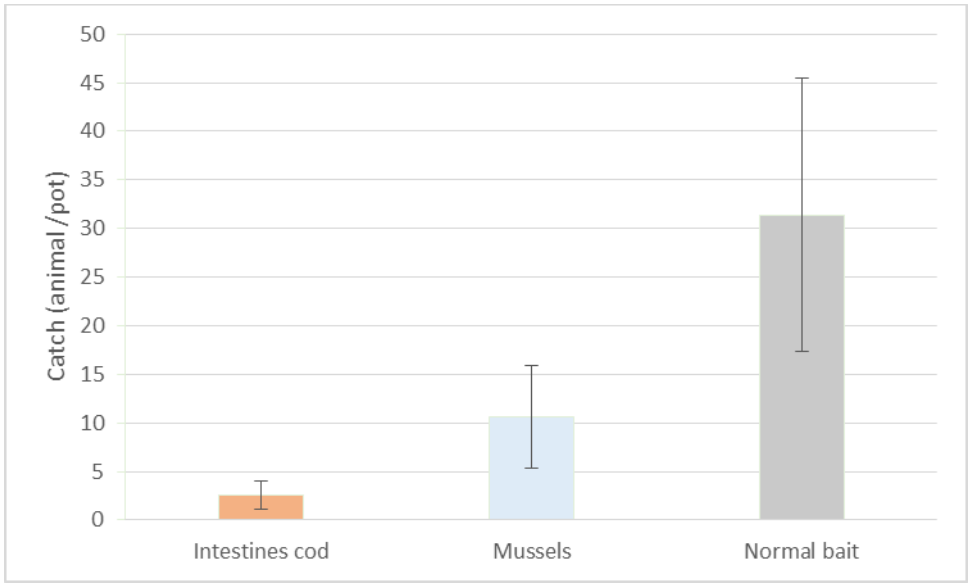

Figure 4 Results from Field test 1, with three different bait (Normal, artificial bait with intestians fron cod and mussels).

2nd field test (February 2019)

The second field test was conducted in February 2019. Pots were baited as previously. Brown crab was used as control (normal bait) in this field trial. The results show that hydrolysates of Brown Crab in the artificial bait had average catch of 24 animal compere to 30 animal using unprocessed brown crab (Normal bait) (Fig.3). A paired t-test gave no significant difference between these two baits (P=0,193, paired t-test). This indicates that the process of making a hydrolysate does not affect the

attractiveness of the bait. The second field test also supports previous findings that more complex composition of amino acids or higher amounts of attractive amino acids e.g. taurine does higher the value of the bait shown buy the better catches of Blue mussel-taurine combination versus blue mussel alone. But still in this test mussel hydrolysate and shrimp hydrolysate had the significant lowest catch compered to brown crab hydrolysate.

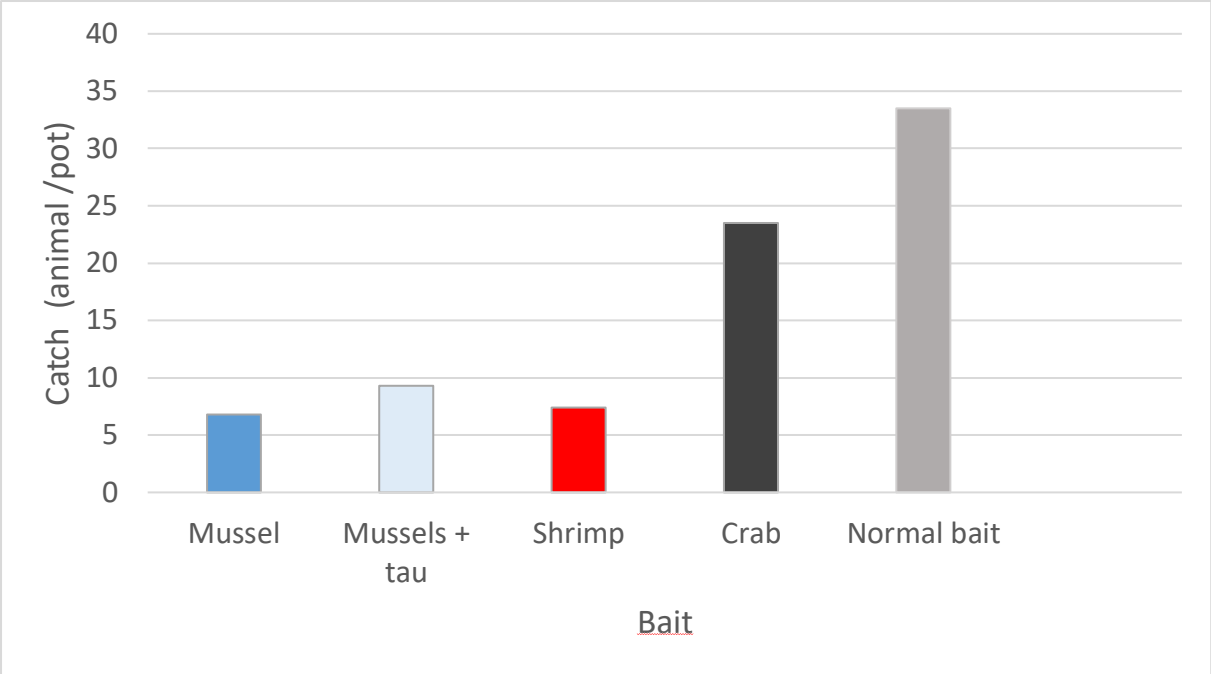

Figure 5 Catches during field test 2, with five different bait (Normal bait, artificial bait with mussels,- mussel with taurine, -brown crab and -shrimps).

3rd field test (october 2019)

In the third field test four different bait types or bait combinations were to be tested. Hydrolysates of Brown Crab legs (BCL), Brown Crab bodies (BCB), whole Green Shore Crab (GSC), and Dogfish (DF). The intention with baits BCL and BCB was to find out if it is the legs or the body of the Brown Crab that is more attractive. Some fishermen say that pots baited with crab legs only fish better than pots with whole crab. We also wished to explore the possibility to substitute Brown Crab in whelk baits with the invasive Green Crab and therefore test a bait based on Green Shore Crab against Brown Crab baits. The third field test was to be conducted in October but due to unexpected circumstances the baits were lost at sea. A new batch of baits have been made and these will be tested later on by fishermen engaged in the project.

Discussion

The studies have illustrated that it is possible to make an artificial dry bait to catch whelk. Lab and field studies gave the same results when it comes to bait preferences. Lab studies can therefore be helpful in the work of finding out which substances to take further and test in field. Brown Crab hydrolysate seems to work well in a bait for catching whelk, with catches comparable with natural bait (whole Brown Crab). This indicates that the process of making a hydrolysate does not affect the attractiveness of the bait and can be used as attractant when making artificial bait. Throughout the project it has become clear that Brown Crab has been and still is a somewhat ultimate bait in the Irish whelk fishery and that the crab contains a combination of particular substances that are very attractive to whelks. What these substances are is not known. It might also be that it is a question of the amount of attractant leaking out more than the substance itself. The amino acid composition analyzis (Table X) does not show any differences between e.g. Shrimp and Brown Crab that would explain why the crab is so attractive. According to literature, whelks have a way of determining the value of a prey but there is little knowledge of the senses a whelk is using to determine if a bait is worth pursuing. There are only a few scientific reports and papers on the chemosensory system of whelks or related molluscans.

Blue mussel included synthetic taurine gave higher catch compered to blue mussel without taurine. Taking single amino acids such as taurine, yields significantly better catches, which indicate that some low molecular substances like free amino acids (taurine) have positive effect on catches. Still taurine included into mussel hydrolysate did not match the brown crab control or hydrolysate of brown crab.

By using the artificial bait we have illustrated that it is possible to control leakage rate of the attractant in two ways; 1) by adjusting the size of the bait it is possible to control the diffusion of odor e.g. increasing the size will increase the diffusion time; 2) or adjust the holes in the bait box, for example by reducing the hole size you will be able to extend the diffusion of odour. Use of manufactured bait gives opportunities to manipulate the leakage rate of odorants, and thereby improved fishing efficiency over a prolonged period of time without replacing the bait.

Recommendations

The field trials as well as the laboratory studies have shown that whelks are fastidious foragers and the odour plume needed to elicit food search behaviour and entrapment of the whelk must be complex and mimic natural bait. To make progress in substituting Brown Crab as bait one direction could be to explore the attractiveness of the Brown Crab further. Recognize what in the Brown Crab that is so attractive and search similar in other more suitable species e.g. shrimp heads. The ultimate goal being a bait with purely synthetic attractants.

The concentration of attracting agent, physical properties of the bait and the amount of bait used needs to be considered in further work on developing alternative baits since the amount of attractant dispersed from a bait at any time is dependent on the bait amount and concentration of attractant. Bait prices will hence depend greatly on amount of raw material needed for reaching the same catch per unit effort as for traditional bait. It has lately been shown that formed bates, based on marine discard can be as effective or even better than traditional baits [42]. However, Karunanithi et al did not discuss the echonomical aspect.

Overal the development of alternativ baits is a multi layered topic with many aspects to concider. Biology of the target spicies, laws, traditions and echonomy. In order to succeed in introducing an alternativ bait all aspects need to be concidered early on.

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Appendix I

Formed Bait Questionnaire Cover Letter

Bait for Irish pot fisheries has become increasingly more expensive and difficult to source as competition for by-products and underutilised species has increased from a range of human and non-human markets. The proposed goal of this project is to develop a cost effective formed bait product primarily for crab and whelk pot fisheries using available by-products in Ireland. BIM, the Crab Fishery Improvement Project and Nofima in Norway, will carry out a project over the next 12 months to develop and test a range of formed bait products under commercial fishing conditions. In order to do this we need to determine:

- What the actual current cost of bait?
- What is used by the industry?
- What volumes are used?
- What are the important attributes of effective bait?
- How much fishermen are willing and able to pay for bait?

It's also important to determine how increasing bait costs and limited availability of bait are impacting on your fishing business. In order to get a better understanding of the main bait issues, we have developed a short anonymous questionnaire and we would be grateful if you could complete this.

Please answer the 15 questions and provide any additional comments that you feel are relevant.

Kind regards,

Michael Cannon BIM

Mobile number 0877416111

Formed Bait Questionnaire V.1

Q1. Which species do you fish?

Brown Crab	☐
Whelk	☐
Lobster	☐
Other, please specify	☐ _____

Q2. What type of bait do you use at the moment?

For Brown Crab _____

For Whelk _____

For Lobster _____

For Other _____

Q3. Please indicate how long are your trips _____

and

How much bait would you use per trip?

Less than 1 Kg	☐
1 – 5 Kg	☐
5 – 10 Kg	☐
10 – 15 Kg	☐
15 – 20 Kg	☐
20 – 50 Kg	☐

Other – Please specify _____

Q4. Is accessing bait a problem? Yes ☐ No ☐

What are the issues, if any:

Q5. How do you currently store your bait and what way would you prefer to store your bait (frozen, dried)?

Q6. What do you like and dislike about the competing bait products on the market?

Q7. What would help you decide to change to a new type of bait?

Q8. Have you used formed Bait before?

Yes ☐

No ☐

What is your opinion on the formed bait?

If yes to Q8: Would you consider using a new formed bait if you are already using a competitors?

Yes	☐
No	☐

If no to Q8: As there are Formed Bait offerings available, why are you not buying them?

Q9. How interested would you be in using a new formed bait?

Not at all interested	☐
Not very interested	☐
Neutral	☐
Somewhat interested	☐
Extremely interested	☐
Not sure	☐

Q10. Which of the following best describes your need for a new formed bait?

Existing bait is becoming too expensive	☐
It is becoming increasingly difficult to source bait	☐
I would like the performance of a targeted bait	☐
I would like the convenience of storage and handling of a formed bait	☐
I have no need for a new bait	☐

Q11. What would you like most about a new formed bait (e.g. convenience, easy storage, and shelf-life)?

Q12. What would you like least about a new formed bait?

Q13. Based on the description, what price would you expect to pay for a new formed bait?

Less than €0.50 per Kg	☐
Between €0.50 and €1 per Kg	☐
More than €1 per Kg	☐

Q14. Would you pay more if the bait performed better?

Yes	☐
No	☐

Q15. What problem do you see formed bait solving that isn't available with other types of bait?

Any other comments