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Efficiency of Industrially Processed Longline Baits

An Ethological Approach

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Contents

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In memory of John M. Bøe 1941 - 2023

Abstract

Industrially processed bait for longline fishing is currently being developed as an alternative to the less sustainable natural bait sources, such as squid and herring. The net catch efficiency of processed baits will depend on the behavior of target fish in phases of interaction, guided by sensory evaluation. In the following, I will evaluate the effectiveness of an ethological approach in determining the relative importance of each of these different behavioral phases for bait efficiency. Herein, direct, and continuous video observations of fish behavior towards baited hooks in the natural environment will be employed. Industrially processed baits (Ecobait variants) will be employed as a model, to be compared to commonly used natural baits. Fish behavior towards these bait categories was categorized and compared, and analyzed to determine to what extent this method can guide further development and improvement of more efficient processed baits. As an additional subgoal, I include metadata on environmental factors (tide, time of day, lunar phase, habitat type, species) for each test occasion, to determine whether there is resolution to also investigate the effect of such factors on behavior towards natural vs processed baits. Natural baits were found to induce a significantly higher frequency of interactions than industrially processed baits, at phases of the interaction cycle corresponding to the fish deeming the bait appetizing and attacking it. Also, regarding behavior towards baited hooks, the degree of contrast between natural and processed baits were found to be affected by both environmental factors and species. For example, fish appeared to be both more active and selective during high and rising tide than during ebb periods. No significant differences were found in the frequency of interactions for early stage, exploratory behaviors. In conclusion, the method utilized in this experiment to gather data was found to yield measurable differences in interaction rates on different bait types allowing for more precise and less resource intensive testing than traditional test fishing.

1. Introduction

1.1 Seafood and sustainability- A global perspective

The human population of Earth is predicted to reach 9.7 billion people by 2050, an increase of nearly two billion people from the current population (United Nations, 2022). Most of this increase will take place in low and middle income countries, which are expected to experience the largest increase in GDP and GDP per capita (Leimbach et al., 2017). Data from previously developed economies has indicated that in such cases, human diets become more protein rich and the share of animal protein compared to total protein intake increases (Andreoli et al., 2021; Grigg, 1995; Henchion et al., 2017). One area that holds promise for sustainable growth is seafood.

A publication by the FAO (2022) reports that just shy of 200 million tons of food from aquatic animals are produced annually. The same report outlined that of the world's wild catch fisheries, just 6% are not overfished or fished at their maximum capacity. Naturally then, one would ask where the increase in aquatic protein could come from. The most intuitive answer seems to be aquaculture, as it is the fastest growing food production industry (FAO, 2022; Gjedrem et al., 2012). Global aquaculture production is nearly equal to that of global wild catch harvest and is expected to surpass wild catch in the near future. This does not mean, however, that one should disregard wild catch entirely, as there is still room for improvement and optimization. One notable advantage of wild catch is that it does not require any form of animal husbandry, driving down associated costs and effort associated with feeding, housing, and care.

The environmental footprints of capture fisheries can however vary significantly, depending on harvesting practices. Marine saltwater harvest from wild catch fisheries was 78.8 million tons in 2020 (FAO, 2022). Of this, roughly 2.4 million tons, or 3%, are caught using longlines (Pauly D., 2020). Fishing with demersal longlines is less disturbing to the benthic habitat, has less bycatch, and is more species selective than other common fishing methods like nets or trawling (Gascoigne & Willsteed, 2009). The fuel consumption of longline fishing vessels per unit catch is higher than that of seine fishing vessels and those that employ other types of nets, yet still lower than or equal to trawling fishing vessels (Boopendranath et al., 2009; Sala et al., 2022; Schau et al., 2009).

A longline is a type of passive fishing gear which consists of a long mainline, with secondary lines, called snoods, attached at fixed intervals (usually 1 - 2 m) going off to the side. Attached to these snoods is a single hook and a piece of bait. Longlines may be as short as a few hundred meters or more than 80 km with thousands of hooks on the largest commercial fishing vessels. The use of longlines varies by region, fishing grounds, and the intended target species. Longlines may be fixed, resting on the bottom, or drifting in the water column. (He, 2021; Nédélec & Prado, 1990).

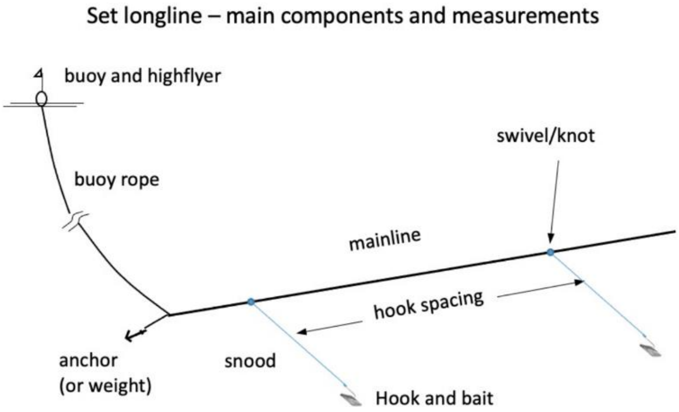

Figure 1: Diagram of a fixed bottom longline. Taken from He et.al. (2021)

The hooks of fixed longlines often rest on the bottom or float near it. In the North Atlantic Ocean, fish species commonly caught on fixed longlines include Atlantic cod (*Gadus morhua*), Atlantic halibut (*Hippoglossus hippoglossus*), Greenland halibut (*Reinhardtius hippoglossoides*), haddock (*Melanogrammus aeglefinus*), ling (*Molva molva*), pollock (*Pollachius pollachius and P. virens*), whiting (*Merlangius merlangus*), cusk (*Brosme brosme*), wolffish (*Anarhichas* spp.), and spiny dogfish (*Squalus acanthias*).

1.2 Longline baits as a key to sustainable harvesting

Longlines are either baited by hand or machines. The choice of bait is one of the most important factors for the efficiency of longline fishing (Løkkeborg, 1989; Løkkeborg & Bjordal, 1992; Sistiaga et al., 2018). Common baits used in the northeast Atlantic are herring (*Clupea harengus*), squid (*Illex* spp.), Atlantic mackerel

(*Scomber scombrus*), or saury (*Cololabis saira*) (Sistiaga et al., 2018). The most used species of squid is Argentine squid (*Illex argentinus*). While herring and mackerel are local, squid and saury are imported from South America and Asia, respectively, which drives up both the cost and the carbon footprint of these baits. As fuel prices and the cost of bait have increased dramatically in recent decades, the development of industrially manufactured long line baits may have a great impact on the future sustainability and profitability of the industry (Løkkeborg et al., 2014).

The Norwegian offshore longline fleet consists of approximately 30 vessels that have their primary fishing grounds along the Norwegian coast and in the North Sea. Each of these vessels has an enormous capacity and can set 60 - 65 000 hooks per day (Nedreaas et al., 2015; Noël et al., 2018). A single fishing vessel may go through 300 to 400 tons of bait per year, and so the cost of bait is a large part of their annual expenses (Sogn-Grundvåg & Hermansen, 2022). These baitfish are of course also edible for humans. If an alternative bait could be produced at a lower cost than the price of natural baits and with a catch rate higher than or equal to that of natural baits, this would reduce a large portion of longlining vessels' operating costs in addition to opening the fish and squid used for bait to instead go towards human consumption.

1.3 Industrially manufactured longline baits

There have been many attempts at producing artificial longline baits over the last few decades. Among other advantages, industrial production allows for the option to choose which attractants to include in the bait, (plus size, and perhaps shape) theoretically allows tailoring each bait to one target species (Løkkeborg et al., 2013; 2014). None of these products, however, have yet been wholly as effective as natural baits. (Løkkeborg et al., 2014). Artificial baits need to contain the necessary attractants to be appetizing to fish and a structure to hold these attractants. This structure needs to be able to release the attractants over a long period of time (several hours) and have the right size, shape, and texture. The structure also needs to be strong enough to withstand fish tugs, scavenging from birds and benthic organisms, all while remaining on the hook. (Løkkeborg et al., 2013; 2014).

Previous attempts at manufacturing longline baits have attempted to solve these problems by several different approaches. The company Norbait used byproducts from the fishing industry bound with alginate, then stuffed into a structural support 'sock' for their attempt at manufacturing an alternative longline bait. They offer different baits intended for different target species. Catch rates of 2-3 times higher than natural baits have been achieved with haddock, though cod showed an aversion towards Norbait bait. A similar experiment conducted by Løkkeborg (1991) used a bait consisting of minced herring bound with guar gum or fish collagen, and found that the bait resulted in a 58% increase in haddock catch, yet also a significantly reduced cod catch. Technical problems regarding mechanical handling have however prevented these baits from being widely used in commercial settings.

An Icelandic company, Bernskan ehf, has a product called Bait Bags (Henriksen, 2009). These consist of ~10 g portions of mixtures of natural bait products and byproducts from fisheries which have been molded together under high pressure. These portions are placed into cellulose fiber bags and are delivered frozen. Tests conducted in Norway compared these bags against mackerel and saury and observed higher catch rates of haddock and poorer catch rates of cod. An advantage of Bait Bags is that scavenging birds do not seem to be as interested in them as in natural baits.

Another attempt at producing an alternative longline bait is described in a patent held by William E.S. Carr (1981). This bait consists of a hydrophilic polyurethane foam with added structural fabric. This bait expands upon contact with water and releases its attractants over a long period of time. Liquid attractants are added to the liquid phase of a colloidal suspension before they form the solid state of the final product. Any attractant may be added if they are in liquid form. This allows for customization of the bait for different target species. This bait was tested on the catch rate of cod in northern Norway. Three sizes of bait were tested, and it was found that the two larger sizes performed poorly compared to natural shrimp bait. The smallest size was found to be as effective as natural bait. A significantly reduced number of smaller cod was caught on the artificial bait, but this is explained by small cod's differing dietary preferences (Løkkeborg et al., 2013).

Ecobait is a new type of bait under development to be used as an alternative or a replacement for traditional natural baits. It incorporates various attractants derived from byproducts from the Norwegian fishing industry in a binding matrix that has been optimized for performance either in an automatic longline baiting machine or in pot traps used for crustaceans.

1.4 Senses and mechanisms affecting bait attractiveness during the different phases of a fish strike

A fish will typically go through a certain set of behaviors before committing to a strike. As outlined in Løkkeborg et.al. (2014) and Hara (1992), the most likely way for a fish to first discover a baited hook is through olfactory cues. Olfaction is one of the most acute senses in fish (Hara, 1994). Olfactory markers vary from species to species, but some common traits among carnivorous fish is that they respond to molecules such as free amino acids, free fatty acids, and a number of products of autolysis within the tissue of the prey item (Løkkeborg et al., 2016). The concentration of scent molecules needs to exceed the threshold values for detection for an individual at that moment in time (Løkkeborg et al., 1995).

As the rate of dispersion in water is much lower than in air, current is the primary driver of odor dispersion in a marine environment. Løkkeborg (1998) showed that cod were able to detect an odor source twice as often when they were downstream, and therefore in the path of the odor stream, compared to those that were upstream of the odor source.

Biotic and abiotic factors affecting behavior towards baited hooks (Løkkeborg et al., 2014; Stoner, 2004).

- Hunger state
- Reproductive status
- Previous experiences
- Diel rhythm
- Light level
- Temperature
- Current
- Prey density

The role of the lateral line is not fully understood in its importance regarding foraging behavior in fish (Løkkeborg et al., 2014). The lateral line is an organ possessed by all fishes which can detect disturbances in the water. The effective range of this is believed to be at most one or two body lengths away from the fish (Kalmijn, 1988). Løkkeborg et.al. (2014) continues and suggests that the lateral line more often plays a larger role in environments where the fish is not able to rely as heavily on its vision, such as in deep water, at night or in turbid waters. As baited hooks display no movement on their own, they will not stimulate the lateral line as much as a live, moving prey item would. However, Montgomery et.al. (1995) outlines how the turbulences created by a static piece of bait upstream of a fish may play a role in the fish's ability to locate the bait.

Further, once the fish approaches the bait and makes visual contact, it may assess the bait using other means than its olfactory sense. The specific behavioral and sensory components of this phase varies based on the species in question (Løkkeborg et al., 1989). Due to poor visibility in most fish habitats due to light absorption by the water or turbidity, fish generally rely less on their vision to make an informed decision on whether to strike at a bait than other senses. Fish of all sizes have been shown be able to spot a prey at longer distances, and are more likely to attack it if the prey is in motion (Løkkeborg et al., 2013). A visual examination of the prey will give the fish information on the prey's size, color, and shape. A further effect of light absorption at depth is that certain colors become muted. Løkkeborg et.al. (2014) outlines how fish use color vision during daylight hours to increase the contrast between the prey and background during hunting. Therefore, the degree to which a fish relies on its visual sense hinges on factors like light intensity, turbidity, and depth. If possible, the fish will also assess the bait's visual characteristics like size, shape, movement, and color. If the fish has deemed the visual and olfactory cues to be appetizing, then it may go in for an attack.

Once a fish has located the bait, it will often conduct a taste test, though this varies by species (Løkkeborg et al., 1989). Taste buds in fish are located on the lips, oral cavity, pharynx, barbels, gills, and fins. Taste helps make the final evaluation of whether to ingest the food item. If the taste is not what the fish expects or prefers, it is apt to spit the bait back out and abandon it (Kasumyan & Døving, 2003). Engulfing the bait all the way will also play a role in allowing the fish to inspect physical characteristics like texture. Once the fish has engulfed the bait, the bait's physical properties further act as determining points on whether the fish swallows the bait. If it can sense the hard and sharp hook protruding from the bait, it may spit the bait back out and either attack it again or abandon it altogether.

1.5 Methods to study bait efficiency

Previous attempts at comparing natural and artificial baits have used several methods to compare the two. Januma et.al. (2003), in a trial onboard a tuna fishing longline boat in the ocean to the southwest of Hawai'i, compared natural squid bait against an artificial bait made from tuna livers stuffed in a gauze pouch. Several baskets were set, each containing nine hooks with a hook spacing of 50 meters. Each basket was baited with one type of bait, meaning that each bait type occupied an approximately 500 m lateral range. No significant difference was observed in the catch rate of tuna in the artificial bait compared to the natural squid bait.

Henriksen (2009) tested cellulose pouches with two types of artificial bait compared to saury and mackerel. 25 days of fishing were conducted over a four-month period in winter off the coast of northern Norway. In eight fishing days spaced evenly over the four-month period, each bait type was used to bait one whole longline at a time, each with 250 hooks and a hook spacing of 2 m. This means that like Januma et.al (2003), each bait type occupied a lateral space of approximately 500 m. In the other 17 fishing days, only one type of bait was used exclusively per fishing trip.

Løkkeborg (1991) outlines an experiment using minced fish with a binding agent stuffed in a nylon bag compared to mackerel natural baits. Test fishing was done onboard commercial longline fishing vessels in the fall off the coast of Ålesund, Norway. The different bait types were tested in approximately 50 hook clusters along the longline. In some trials, every third hook (even among the bait bags) was baited with squid, as this has been shown to increase catch rates if used in conjunction with mackerel (Franco et al., 1987).

Common to the aforementioned approaches are that only catch rates are registered, and it cannot be identified at which point in the interaction cycle a bait type fails or succeeds.

In Løkkeborg (1990), two artificial baits of different shapes were tested against one another. Each bait was made from minced mackerel and stuffed into differently shaped nylon mesh bags. Data for this trial was gathered by utilizing a camera attached to a fixed rig resting on the seafloor. The rig consisted of a frame with the camera mounted vertically and a longline emanating from the rig. The longline had four hooks attached to 35 cm snoods which were spaced 35 cm apart on the longline. Each hook was then baited with the two types of bait, alternating between them. The video captured during these trials was then analyzed later to determine cod's behavior towards the different shapes of bait presented.

A similar trial was conducted and is described in Løkkeborg (1989). In this trial, a camera was mounted horizontally to a metal frame placed on the seabed underneath the Albuskjell 1/6 A oil rig in the North Sea, observing hooks baited with baited with alternating manufactured and natural baits. Due to a lack of interactions with the artificial baits, only interactions with the natural baits were included in the experiment.

1.6 Thesis goals

In an ongoing collaboration between NMBU and Ecobait AS, a knowledge gap was identified regarding the full understanding of the diversity of factors which may affect bait efficiency. Catch rates have been observed to vary considerably between different test protocols and production batches. A test program must therefore be designed to determine the relative efficiency of different sources of raw material, attractants, and production methods.

In this thesis, I evaluate a suggested ethological approach, using direct video observations of fish behavior towards baited hooks as a tool to identify the proximate mechanisms that determine whether different bait types are more successful in catching fish than others.

In addition to methodological considerations, I provide in the discussion a short review of biological and environmental factors which control and affect the strike behavior of predatory fish to food items. Empirical observations are then discussed with regards to this knowledge base.

2 Materials and method

2.1 Data collection

Data collection for this project was completed around Måløy in western Norway. Most data were collected in August and September of 2022, with some additional observations having been completed in May and June.

Four or six Mustad 2330DT size #5 longline hooks with a braided polyester snood (2,5 mm x 30 cm) were attached to a welded metal rig (pictured in Figure 2) with 29 cm spacing. The rig consisted of a 2 m long horizontal steel beam, raised 80 cm off the ground by two legs, with perpendicular feet for stability. Also attached to the rig was an arm which extended out to the front and with a mount for a waterproof housing for a GoPro HERO 9 camera and a diving flashlight with red plastic film taped over the lens. The camera housing also included space for an external battery pack. The camera was mounted horizontally and pointed inward so that it gave a view of all four or six hooks underneath the beam. In the center of the main horizontal beam, a rope was attached with a buoy on the other end. To mimic the wide variety of natural baits used on commercial fishing vessels, a wide array of natural baits was used in this experiment. Baits used over the course of the experiment were: herring, squid, saury, and mackerel. Too little data exists to compare these individually, and therefore they have been combined into the category of

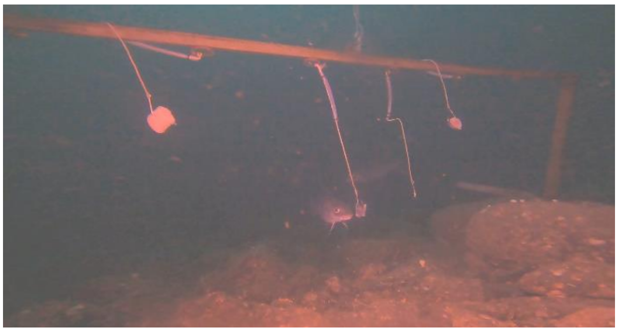

Figure 2: Image of the camera rig used for fish observations during this trial. A haddock is inspecting a piece of herring.

“Natural Baits”. Rigs were always baited with one type of natural bait and one type of Ecobait, alternating between every hook.

The filming took place in locations with a wide array of abiotic factors. Rigs were placed at depths ranging from 8 to 120 m with individual recordings lasting between 48 to 772 minutes. Effective time to be incorporated in unit effort (=hours of active fishing observed per baited hook) was also sometimes limited by bait being removed from the hook, or the hook being occupied by hooked fish. The reason for a hook being rendered out of commission was recorded and categorized. From a total of 7941 minutes (132.4 hours) of recorded videos, observed interactions between fish and the baited hooks were categorized into five behavioral interaction categories. The possible interactions were “Snout”, “Nip”, “Engulf lost”, “Engulf spit”, and “Hooked”, defined in the following.

2.2 Interaction categories

“Snout” was counted as an interaction where the fish bumped the bait in question with its snout yet made no move to interact with its mouth. “Nip” was counted as a partial engulfment, often just a taste or nibble on the corner of the bait. “Engulf lost” was an interaction characterized by the complete engulfment of the bait, followed by the fish not immediately swallowing it, but attempting to swim elsewhere with the bait still in its mouth. The bait, being still attached to the rig, was then pulled from the fish’s mouth without the hook catching in the tissue. “Engulf spit” was an interaction characterized by a complete engulfment of the bait followed by the fish then actively spitting the bait back out. The distinction between “Engulf lost” and “Engulf spit” was made based on whether the bait being lost was intentional or not. “Hooked” was simply an instance of the fish being hooked and unable to swim away despite obvious active attempts. If a fish became hooked, and then came loose at a later time, the interaction was still regarded as “Hooked”. The values for “Engulf lost”, “Engulf spit”, and “Hooked” were also combined to form the category “Engulf total”. This would include every interaction where a fish fully engulfed the baited hook, i.e., an instance that could potentially lead to capture.

Only interactions with species of economic significance were counted. The species observed over the course of this trial were haddock, ling, pollock (*P. pollachius* and *P. virens*), whiting, cusk, and spiny dogfish. Only fish that physically interacted with the bait were counted.

Fish would often have multiple interactions with the same bait. This could be in the form of multiple rapid interactions, or an interaction followed by a move away from the bait before returning and interacting with the same bait again. Two interactions from the same fish were counted as separate interactions if the fish moved further than one body length away from the bait it had interacted with. If a fish approached a hook and displayed multiple “Nip” interactions without moving one body length away, only one was counted. Fish would also often exhibit more than one interaction type on a single visit to a hook. When this was the case, only the interaction type that came latest in the attack sequence was counted as having occurred. For example, if a fish approached a baited hook and had a “Snout” interaction with the hook followed by a “Nip” interaction, without moving more than one body length away, the interaction was recorded as a “Nip”. Similarly, if a fish displayed a “Engulf spit” interaction followed by another engulfment which led to the fish being hooked, the interaction was counted as a “Hooked” In terms of their order in the attack sequence, “Snout” was given a value of one, “Nip” was given a value of two, “Engulf lost” and “Engulf spit” were given a value of three, and “Hooked” was given a value of four.

2.3 Data analysis

Due to rigs being set by multiple people and some data being absent from many recordings, the depth at which every rig was set was not recorded. The same is true for the length and weight of fish caught. If provided in the recording, the time and date were noted. It not, the time, date, and length of the recording were accessed through the video files’ metadata. This was then used to calculate the length of time each rig spent in different tide phases, moon phases, and phases of the day. Based on the video, the habitat type and fish species were determined. The habitat categories encountered were “Mud”, “Sand”, “Rock”, and “Kelp”. No bait interactions occurred in the “Kelp” habitat. Data for this habitat type are therefore disregarded in further habitat analyses.

Video files were reviewed, and each interaction was categorized. The timestamp, species, interaction type, and bait type were recorded for each interaction. Interactions per individual hook were not recorded, but rather per hook group. A hook group is defined as all the hooks on a single camera rig with the same type of bait. Each rig had two hook groups per set, one group for natural bait and one group for Ecobait. Each hook group contained 1-3 hooks. This discrepancy is due to some rigs having six hooks in view in the video (three hooks in each group) and some only having three hooks visible (two baits in one group and one in the other). This is due to a flaw in the camera rig design, not accounting for light refraction being different underwater and in air, zooming the image in when underwater. Hook groups for each rig were then further divided into categories corresponding to either the tide phases encountered by that rig set or into categories corresponding to the times of day encountered by that rig set.

The number of interactions per interaction type were then converted into interactions per hook hour for each hook group. A hook hour is regarded as one hour where a single hook is actively fishing, i.e., with a piece of bait attached and not occupied by a hooked fish. If a hook were to have its bait removed, the timer for that hook would be stopped, and it would then no longer contribute to the count of hook hours in that hook group for the remainder of that rig set. Hook hours for each hook group were calculated for time per tide phase and time per day phase. Hook hours per group for lunar phase and habitat type did not change over the course of a rig set and were therefore simply added together. The species available to interact with the baited hooks likewise did not change over the course of a rig set and the interaction frequencies were therefore also summed for each hook group per hook hour.

The tide phases encountered per hook set was determined by finding the start and end time for each recording, and then comparing that to a chart of tide phases for Måløy provided by the Norwegian Mapping Authority (2021). The categories of “High tide” and “Low tide” were defined to be from one hour before to one hour after the peak/nadir times provided in the chart. “Rising tide” and “Falling tide” were deemed to be the time in between these two periods.

Phases of the day were determined by consulting a table of times for sunrise and sunset in Måløy (Stjerneskinn, 2022). The table provided times for different definitions of dawn and dusk. For this analysis, the complete definition of dawn and dusk was used, called astronomical dawn and dusk. This is marked by the times when the geometric center of the sun moves more than 18° below the horizon. For recordings made in the summer, when true night never occurred over the course of a day, the dividing line between dusk and dawn was set to be solar midnight.

The phases of the moon were determined by consulting a table of lunar cycles for Måløy (Time and Date, 2022). The table provided exact times for when each quarter of a lunar cycle started. The middle between these times was then calculated to get the phases “New moon”, “Waxing gibbous”, “Full moon”, and “Waning gibbous”. This was done so that the phases “New moon” and “Full moon” accounted for the quarter of the lunar cycle in which the moon was at its darkest or brightest, respectively. The moment of maximum darkness or maximum brightness occupied the middle of these two phases. “Waxing” and “Waning” would then occupy the quarters in transition between “New moon” and “Full moon”. No recordings were made during the “Waxing” phase.

Behavioral data (interactions in each category per hook hour) were analyzed using a GLM approach in an ANOVA model. This was used to determine values for Least Square means, which were used to compare the different bait types against one another. A p-value of 0.05 was set as being statistically significant.

3 Results

3.1 Overall patterns

A total of 29 rig sets were analyzed encompassing a total of 466 hook hours, of which 195.5 hook hours included hooks baited with natural baits and 270.5 hook hours of hooks baited with Ecobait. Table 1 shows the number of observed interactions per

Table 1: Interactions per hook hour in aggregate. Numbers in bold indicate a statistically significant difference between bait types.

Bait type	Hook hours	Snout	Nip	Engulf lost	Engulf spit	Hooked	Engulf total	**Total**
Natural bait	195,5	0,018 ± 0,012	0,27 ± 0,14	0,13 ± 0,081	0,021 ± 0,015	0,18 ± 0,096	**0,33 ± 0,13**^{a}	0,62 ± 0,26
Ecobait	270,4	0,042 ± 0,014	0,16 ± 0,057	0,0053 ± 0,0031	0,0029 ± 0,0021	0,015 ± 0,0063	**0,023 ± 0,0072**^{b}	0,22 ± 0,064

hook hour, for the different behavioral interaction categories. Only the behavioral pattern designated as “Snout” occurred numerically more frequently in relation to hooks baited with Ecobait, though this was not statistically significant (p = 0.215). Due to high intracategory variation, only the combined variable “Engulf total” was found to show a significantly higher number of observations per hook hour for natural baits compared to Ecobait in the overall data. (p = 0.019).

3.2 Environmental effects

3.2.1 Tide phase

Table 2 shows the frequency of each interaction type per hook hour when data were categorized with regards to tidal phase during recording. Natural baits now induced significantly or near significantly more interactions than Ecobait in the categories “Engulf lost” (p = 0.032) and “Total” (p = 0.054) during “High tide”, and for “Hooked” (p = 0.047) during “Rising tide”. Hooks baited with natural baits saw significantly more interactions per hook hour in the “Nip” category (p = 0.049) during “High tide” compared to “Low tide” (Figure 3).

Table 2: Interactions per hook hour for different tidal phases. Numbers in bold indicate a statistically significant difference between bait types.

Tide phase	Bait type	Hook hours	Snout	Nip	Engulf lost	Engulf spit	Hooked	Engulf total	**Total**
Low tide	Natural bait	23,6	0 ± 0	0 ± 0	0,010 ± 0,010	0 ± 0	0,071 ± 0,058	0,081 ± 0,058	0,081 ± 0,058
	Ecobait	28,7	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Rising tide	Natural bait	75,8	0,014 ± 0,010	0,14 ± 0,057	0,072 ± 0,049	0,044 ± 0,039	**0,37 ± 0,28**^{a}	0,48 ± 0,29	0,64 ± 0,29
	Ecobait	104,5	0,067 ± 0,0061	0,21 ± 0,022	0,0065 ± 0,0040	0 ± 0	**0,042 ± 0,025**^{b}	0,049 ± 0,025	0,32 ± 0,039
High tide	Natural bait	31,2	0,059 ± 0,046	0,66 ± 0,55	**0,34 ± 0,32**^{a}	0,028 ± 0,027	0,048 ± 0,046	0,42 ± 0,37	**1,14 ± 0,96**^{a}
	Ecobait	51,7	0,022 ± 0,021	0,089 ± 0,087	**0 ± 0**^{b}	0,0074 ± 0,0071	0 ± 0	0,0074 ± 0,0071	**0,12 ± 0,090**^{b}
Falling tide	Natural bait	66,2	0 ± 0	0,28 ± 0,17	0,097 ± 0,062	0,0018 ± 0,0018	0,12 ± 0,072	0,22 ± 0,11	0,50 ± 0,23
	Ecobait	83,3	0,055 ± 0,025	0,26 ± 0,15	0,012 ± 0,0086	0,0043 ± 0,0042	0,0025 ± 0,0024	0,019 ± 0,011	0,33 ± 0,16

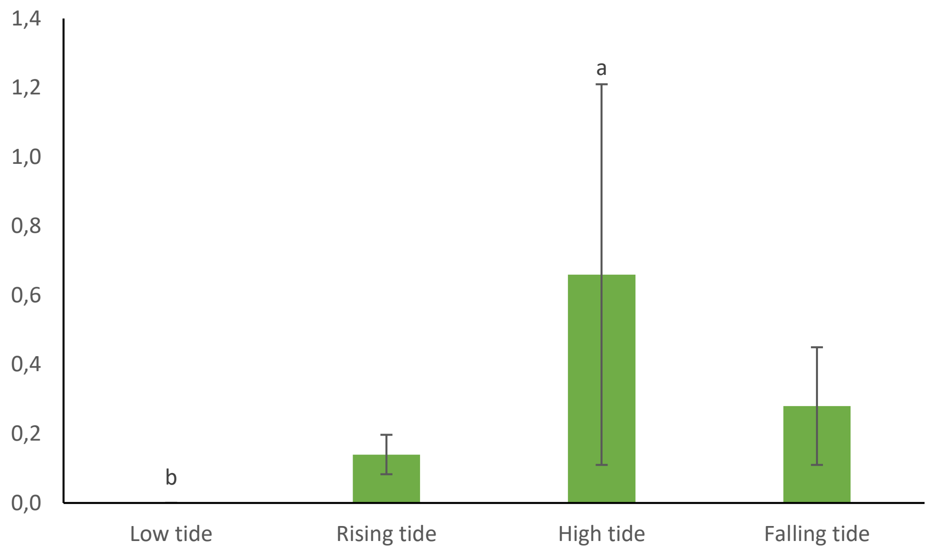

Figure 3: The frequency of the interaction "Nip" per hook hour on hooks baited with natural baits for different tidal phases. "High tide" experienced significantly more interactions per hook hour than "Low tide."

3.2.2 Day phase

Table 3 shows the frequency of interaction types per hook hour based on the phases of the day that were examined. Significantly more fish were observed to interact with hooks with natural bait during daylight hours for the categories of "Engulf lost" (p = 0.008) and "Engulf total" (p = 0.016). Natural baits also saw significantly more interactions during daylight hours than during "Dusk" (p = 0.050) (Figure 4).

Table 3: Interactions per hook hour for different day phases. Numbers in bold indicate a statistically significant difference between bait types.

Day phase	Bait type	Hook hours	Snout	Nip	Engulf lost	Engulf spit	Hooked	Engulf total	**Total**
Dawn	Natural bait	22,6	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	Ecobait	26,0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Day	Natural bait	132,5	0,034 ± 0,027	0,39 ± 0,16	**0,12 ± 0,051^a**	0,029 ± 0,021	0,33 ± 0,23	**0,48 ± 0,24^a**	0,91 ± 0,30
	Ecobait	178,7	0,20 ± 0,13	0,39 ± 0,16	**0,013 ± 0,0076^b**	0,0056 ± 0,0039	0,018 ± 0,011	**0,036 ± 0,013^b**	0,63 ± 0,28
Dusk	Natural bait	36,3	0,0082 ± 0,0082	0,0059 ± 0,0059	0,033 ± 0,025	0,016 ± 0,016	0,014 ± 0,0096	0,064 ± 0,049	0,078 ± 0,057
	Ecobait	53,2	0,031 ± 0,031	0 ± 0	0 ± 0	0 ± 0	0,0045 ± 0,0045	0,0045 ± 0,0045	0,036 ± 0,031
Night	Natural bait	4,1	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0,074 ± 0,074	0,074 ± 0,074	0,074 ± 0,074
	Ecobait	12,6	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0

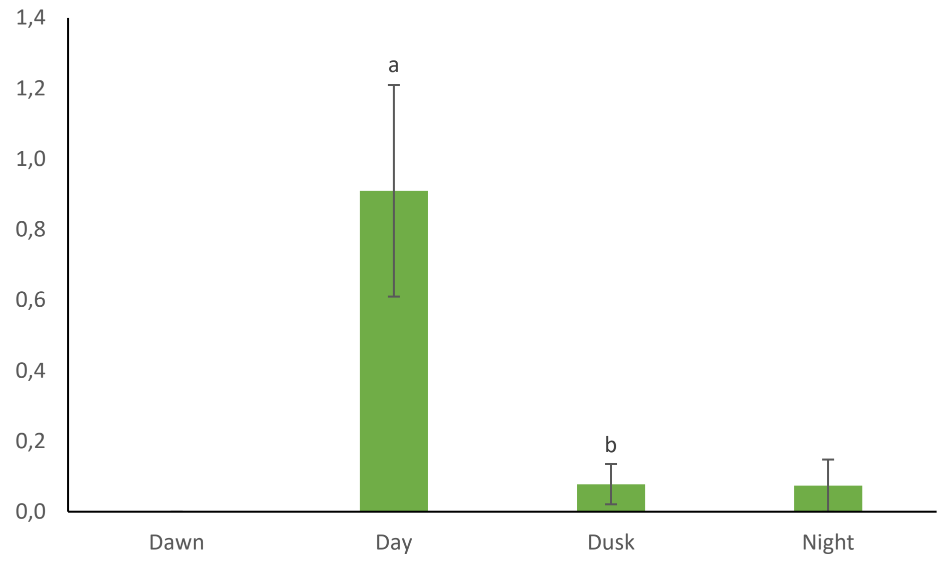

Figure 4: The frequency of the total number of interactions per hook hour on hooks baited with natural baits for different day phases. "Day" experienced significantly more interactions per hook hour than "Dusk."

3.2.3 Lunar phase

A significantly higher frequency of interactions was observed on hooks with natural baits than hooks baited with Ecobait for the interaction types "Engulf lost" (p = 0.044), "Hooked" (p = 0.042), and "Engulf total" during the lunar phase of "New moon". This may be seen in Table 4. Hooks baited with natural baits had significantly more hooked fish (p = 0.046), total engulfments (p = 0.0071), as well as total interactions (p = 0.015) per hook hour during "New moon" than during "Waning gibbous". This may be seen in Figure 5. The same trend was observed with hooks baited with Ecobait, though this was not found to be statistically significant due to high variation.

Table 4: Interactions per hook hour for different lunar phases. Numbers in bold indicate a statistically significant difference between bait types.

Moon phase	Bait type	Hook hours	Snout	Nip	Engulf lost	Engulf spit	Hooked	Engulf total	**Total**
New moon	Natural bait	68,4	0,040 ± 0,029	0,47 ± 0,34	**0,26 ± 0,20**^{a}	0,037 ± 0,034	**0,34 ± 0,24**^{a}	**0,63 ± 0,33**^{a}	1,15 ± 0,63
	Ecobait	77,5	0,062 ± 0,032	0,26 ± 0,12	**0,0059 ± 0,0059**^{b}	0 ± 0	**0,027 ± 0,015**^{b}	**0,033 ± 0,016**^{b}	0,36 ± 0,13
Full moon	Natural bait	63,6	0,0088 ± 0,0088	0,25 ± 0,15	0,080 ± 0,054	0,022 ± 0,022	0,13 ± 0,069	0,24 ± 0,10	0,49 ± 0,20
	Ecobait	72,3	0,043 ± 0,026	0,17 ± 0,14	0,0041 ± 0,0041	0,011 ± 0,0076	0,010 ± 0,010	0,025 ± 0,014	0,24 ± 0,15
Waning	Natural bait	63,6	0 ± 0	0,038 ± 0,029	0,016 ± 0,0093	0,0015 ± 0,0015	0,014 ± 0,0089	0,032 ± 0,016	0,069 ± 0,032
	Ecobait	120,6	0,021 ± 0,013	0,045 ± 0,028	0,0055 ± 0,0055	0 ± 0	0,0060 ± 0,0045	0,012 ± 0,0070	0,078 ± 0,042

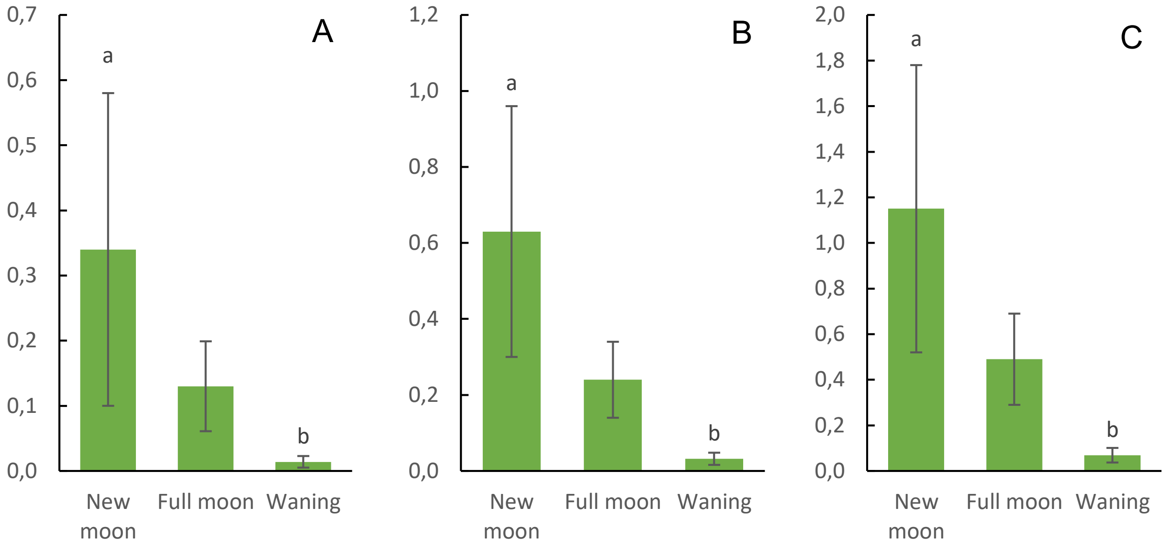

Figure 5: The frequency of the interaction "Hooked" (A), total engulfments (B), and total interactions (C) per hook hour on hooks baited with natural baits for different lunar phases. "New moon" experienced significantly more interactions per hook hour than "Waning" for all these interaction categories.

3.2.4 Habitat type

Table 5 shows the number of each interaction type per hook hour based on which habitat type the interactions were recorded in. A statistically significant difference occurred in the habitat type of "Rock" in the ratio of interactions between natural baits and Ecobait for the interaction type of "Engulf spit" (p = 0.002). The same relationship was observed in sandy habitats for the interaction "Engulf total" (p = 0.018). Hooks baited with natural baits saw significantly more interactions per hook hour in the category "Engulf spit" in rocky habitats compared to habitats with mud (p = 0.0001) and sand (p = 0.0005) (Figure 6).

Table 5: Interactions per hook hour for different habitat types. Numbers in bold indicate a statistically significant difference between bait types.

Habitat	Bait type	Hook hours	Snout	Nip	Engulf lost	Engulf spit	Hooked	Engulf total	**Total**
Mud	Natural bait	91,5	0 ± 0	0,20 ± 0,11	0,059 ± 0,038	0,0011 ± 0,0011	0,060 ± 0,034	0,12 ± 0,065	0,32 ± 0,14
	Ecobait	119,3	0,021 ± 0,013	0,18 ± 0,10	0,0082 ± 0,0059	0,0029 ± 0,0028	0,024 ± 0,013	0,035 ± 0,014	0,23 ± 0,11
Sand	Natural bait	85,1	0,038 ± 0,024	0,38 ± 0,27	0,19 ± 0,16	0,016 ± 0,013	0,27 ± 0,19	**0,48 ± 0,26^{a}**	0,90 ± 0,50
	Ecobait	101,0	0,070 ± 0,029	0,20 ± 0,093	0,0048 ± 0,0047	0,0040 ± 0,0040	0,011 ± 0,0082	**0,020 ± 0,0099^{b}**	0,29 ± 0,10
Rock	Natural bait	20,3	0 ± 0	0 ± 0	0,14 ± 0,13	**0,14 ± 0,13^{a}**	0,21 ± 0,11	0,49 ± 0,31	0,49 ± 0,31
	Ecobait	21,4	0,032 ± 0,029	0 ± 0	0 ± 0	**0 ± 0^{b}**	0,0065 ± 0,0059	0,0065 ± 0,0059	0,039 ± 0,035

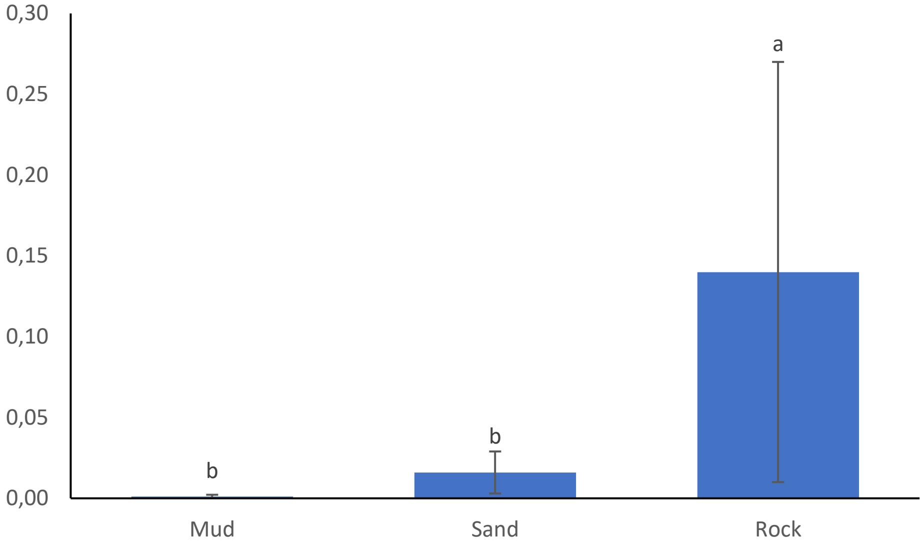

Figure 6: frequency of the interaction "Engulf spit" per hook hour on hooks baited with natural baits for different habitat types. "Rock" experienced significantly more interactions per hook hour than both "Mud" and "Sand."

3.3 Interactions by species

The interaction frequency based on species is presented in Table 6. Haddock displayed more interactions per hook hour with natural baits for the interaction types of "Engulf lost" (p = 0.003) and "Engulf total" (p = 0.036). Ling had significantly more interactions per hook hour with natural baits for the interaction types "Engulf spit" (p = 0.003), "Hooked" (p = < 0.0001), and "Engulf total" (p = 0.0004).

Table 6: Interactions per hook hour for the different species encountered. Numbers in bold indicate a statistically significant difference between bait types.

Species	Bait type	Snout	Nip	Engulf lost	Engulf spit	Hooked	Engulf total	**Total**
Haddock	Natural bait	0,071 ± 0,050	0,82 ± 0,36	**0,18 ± 0,13**^{a}	0,036 ± 0,025	0,054 ± 0,030	**0,27 ± 0,15**^{a}	1,16 ± 0,52
	Ecobait	0,19 ± 0,080	0,65 ± 0,20	**0 ± 0**^{b}	0 ± 0	0,063 ± 0,031	**0,063 ± 0,031**^{b}	0,90 ± 0,26
Ling	Natural bait	0,036 ± 0,035	0 ± 0	0,13 ± 0,067	**0,13 ± 0,095**^{a}	**0,16 ± 0,061**^{a}	**0,41 ± 0,20**^{a}	0,45 ± 0,23
	Ecobait	0,11 ± 0,084	0 ± 0	0,032 ± 0,022	**0,016 ± 0,016**^{b}	**0,016 ± 0,016**^{b}	**0,063 ± 0,031**^{b}	0,17 ± 0,10
Pollock (*P. pollachius*)	Natural bait	0 ± 0	0 ± 0	0,054 ± 0,053	0 ± 0	0 ± 0	0,054 ± 0,053	0,054 ± 0,053
	Ecobait	0,11 ± 0,084	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0,11 ± 0,084
Pollock (*P. virens*)	Natural bait	0 ± 0	0,36 ± 0,30	0,018 ± 0,018	0 ± 0	0,054 ± 0,039	0,071 ± 0,043	0,43 ± 0,31
	Ecobait	0 ± 0	0,13 ± 0,13	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0,13 ± 0,13
Whiting	Natural bait	0 ± 0	0,25 ± 0,25	0,054 ± 0,053	0 ± 0	0 ± 0	0,054 ± 0,053	0,30 ± 0,30
	Ecobait	0 ± 0	0,41 ± 0,41	0,016 ± 0,016	0,016 ± 0,016	0 ± 0	0,032 ± 0,031	0,44 ± 0,44
Cusk	Natural bait	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	Ecobait	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0,032 ± 0,022	0,032 ± 0,022	0,032 ± 0,022
Spiny dogfish	Natural bait	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0,018 ± 0,018	0,018 ± 0,018	0,018 ± 0,018
	Ecobait	0,048 ± 0,035	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0,048 ± 0,035

3.4 Hooks out of commission

A total of 119 hooks were baited for this experiment, 56 of which were baited with natural baits and 63 with Ecobait. Of these hooks, 39 lost their bait over the course of the recording. The reason for the bait being removed based on bait type is presented in Figure 7. 22 hooks baited with natural baits had their bait removed and 17 hooks baited with Ecobait. The most common reasons for hooks being rendered out of commission for natural baits were a fish being hooked, which accounted for 45.5% of all decommissions, and being removed by a fish, which accounted for 31.8% of all decommissions. Hooks baited with Ecobait had a more even split, with being removed by a fish, and falling off with no external stimuli accounting for 29.4% of all decommissions each.

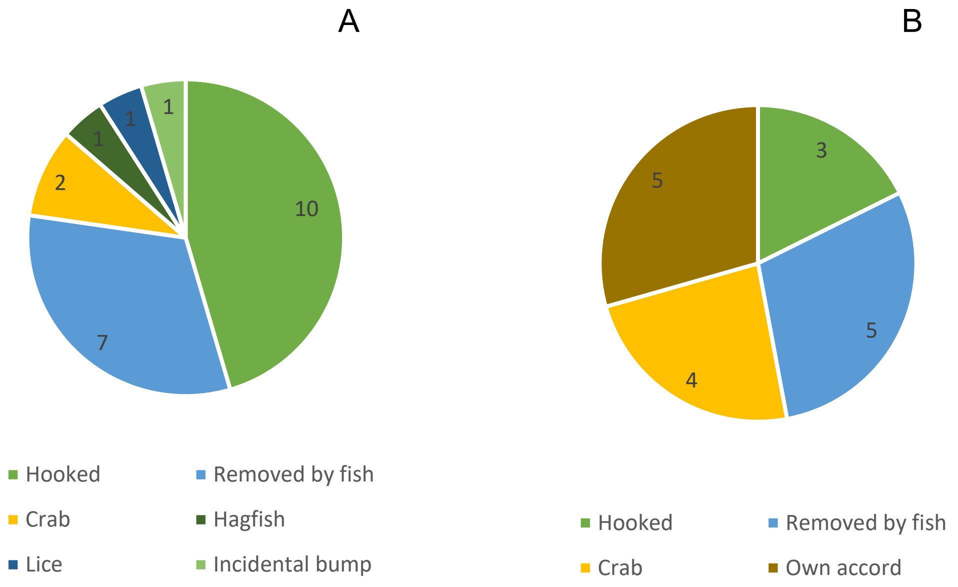

Figure 7: The causes for pieces of bait being removed from their hooks for hooks baited with natural baits (A) and Ecobait (B).

4 Discussion

4.1 Overall patterns

Multiple statistically significant differences were found to be present between natural baits and Ecobait over the course of this experiment. This is true for multiple interaction categories, and in line with data from extensive test fishing using commercial vessels, for the types of processed bait made available for this study (new video recordings are presently being produced for bait types showing catch efficiency similar to or exceeding natural bait). The data therefore seems to indicate that it is a valid way to test and compare two different bait types in a scaled back and less resource intensive manner, compared to large scale test fishing. Moreover, using test rigs in this way makes it possible to test fishing performance in a wide range of habitats, and determine which particular bait characteristics are determining the catch outcome at different stages of the behavioral attack cycle.

Though not significant for every category, the frequency of interactions for hooks baited with natural baits was higher than for hooks baited with Ecobait for nearly every interaction category.

4.2 Ability of compared baits to induce “Exploratory” actions versus "Attack” behaviors

Numerically, interactions for the category “Snout” and “Nip” are about equal or slightly in favor of Ecobait hooks. This cannot be said for the categories “Engulf spit”, “Engulf lost”, and “Hooked” (collectively “Engulf total”), which are heavily weighted in favor of natural baits. Notably, the “Engulf” categories are those that are most likely to result in an actual hooking. The first two interaction categories may be classified as occurring while a fish is still in “Food foraging mode” whereas the latter three may be seen as being in a later stage of foraging behavior, here called “Attack mode”. This seems to indicate that the Ecobait product types tested here possess the necessary traits to be attractive and enticing, but not quite capable of triggering a consummatory strike. The primary attractants of Ecobait are concentrated water soluble hydrolysis products and amino acids, like what Løkkeborg et.al. (2016) indicated as being the main attractants for carnivorous fish.

Ecobait seems to be viewed as enticing by fish and capable of triggering exploratory interactions to determine its edibility. Ecobait looks different from anything that a fish would naturally encounter during normal food forage behavior, and therefore the fish is likely to perform an analysis before attacking. Kasumyan et.al. (2003) states that fish have taste buds on their fins, lips and barbels, all of which are used to survey food items before ingestion. This is likely the action observed in “Snout” interactions. Overall, interactions in the “Snout” category occurred nearly six times more often on hooks baited with Ecobait than natural baits. While the ratio between the two bait categories varied in its weight in favor of Ecobait, this trend continued for every tidal, lunar, and day phase, as well as per habitat, except for during “High tide”. The difference between the two bait categories never became large enough to be statistically significant with the number of observations available for analysis in this experiment.

The second interaction type performed in “food foraging mode”, “Nip” did not see a favorability towards Ecobait, unlike what was observed in “Snout”. Instead, interactions were roughly equal between Ecobait and natural baits. This was the only interaction category where this was the case. This trend persisted for every environmental category, save for “High tide”, where the number of nips seemed to skew towards natural bait. Only two nips were recorded on Ecobait for this timeframe while 19 were recorded on natural baits. Due to high variation within the dataset, this ratio was not seen as statistically significant (p = 0.063), though the numerical difference is notable.

Interactions in the final three categories, “Engulf lost”, “Engulf spit”, and “Hooked” (together “Engulf total”) showed a consistent numerical favorability towards natural baits. These three interaction types differ from “Snout” and “Nip” in that they are behaviors associated more with an acceptance of the bait as a favorable food item, and the fish moving in towards an attack. Given that interaction numbers for Ecobait are higher or equal to those of natural baits for “Exploratory” actions and not for “Attack” behaviors, this seems to indicate that one or more traits of desirability are missing that entice fish to make the leap from “Explore” to “Attack”. Since this change is most acutely seen at this junction, seemingly, the olfactory cues of Ecobait are not the issue, but rather visual or mechanical in nature.

As mentioned previously, the appearance of Ecobait does not match the natural prey items of carnivorous fish. Løkkeborg et.al. (2013) states that fish have an image of known prey in their mind, and therefore would have no basis of knowledge for the appearance of Ecobait. Numerous studies have indicated that the shape of bait influence the strike rate, regardless of olfactory and gustatory attractants (Løkkeborg, 1991; Løkkeborg et al., 2013). The degree to which the strike rate on Ecobait is primarily rooted in its visual or mechanical characteristics needs further studies to determine. One advantage of Ecobait is that it does not consist of an attractant stuffed in a containment bag, as this has been found in numerous studies to reduce strike rates compared to conventional longline baits (Løkkeborg, 1989; S Løkkeborg, 1990; Svein Løkkeborg, 1990; Løkkeborg, 1991; Løkkeborg et al., 1989).

4.3 Effect of environmental factors on bait interactions

4.3.1 Effect of the tides on bait interactions

The tides are a major abiotic factor that has a great effect on fish locomotion and feeding habits. Tides act as the primary vector for odor dispersal over long distances, resulting in scent being the determining factor for attracting fish from afar. Fish that are downstream from the odor source have to swim against the current in order to reach the odor source. It may therefore be advantageous to wait for the current to subside in order to conserve energy (Løkkeborg et al., 2014; Stoner, 2004). Furthermore, several important species appear to have a vertical migration linked to the tides (Michalsen et al., 1996).

In the current experiment, During the tidal phases of “Rising” and “High”, significantly more interactions were recorded on hooks baited with natural baits compared to hooks baited with Ecobait. More interaction categories were not significant due to high variance within the data sets, though this might have been mitigated with more observations. The trend for every tide category seems to be that fish interact more often with natural baits than artificial baits.

No significant difference was observed between bait types in periods of high current (rising and falling tide) and periods of low current (high and low tide), though this may be due to inadequate data. The only significant difference between tidal phases is to be found in the category “Nip” on natural baits between “High tide” and “Low tide”. No observations were recorded during “Low tide” versus 19 for “High tide”, yielding values for nips per hook hour of 0 vs 0.66. This seems to suggest that fish are more active during high tide and searching for food. The frequency in just the “Nip” category alone during “High tide” (0.66) is higher than the value for all interactions combined (“Total” category) during “Rising tide” (0.64), which corroborates statements made by Løkkeborg (2014) and Stoner (2004) that fish are less active during periods of high current.

Around twice the frequency of “Total” interactions was recorded during “High tide” than the frequency recorded during “Rising tide” and “Falling tide”, and more than 14 times as many as during “Low tide”. Løkkeborg (2014) suggests that higher catch rates may be achieved by setting longlines during tidal phases with moderate current. This would maximize the concentration of olfactory molecules in the water during the time frame where the current is the least likely to inhibit fish movement.

4.3.2 Effect of time of day on bait interactions

No interactions were observed during the day phase “Dawn”, despite 22.6 hook hours being recorded with natural baits and 26 hook hours being recorded with Ecobait at this time. This stands in contrast to observations made by Løkkeborg et.al. (1997; 2000) and Ward et.al. (2004) where longlines saw an increased catch rate for numerous common longlining species during dawn. An explanation for this might be found in (Løkkeborg & Bjordal, 1992) and (Bjordal & Løkkeborg, 1996), where the authors suggest that the attractant molecules dissipate over time and are no longer as concentrated as when they are first submerged underwater. No rigs were set in the hours leading up to dawn through the course of this experiment, and therefore all bait that was in the water during “Dawn” hours were at least several hours old. Observations made in Løkkeborg et.al. (1997) seemed to indicate that environmental factors rather than soak time had a greater impact on catch rates.

Aglen et.al. (1999) and Adlerstein et.al. (2002) indicate that multiple species, e.g., small haddock, make a vertical diurnal migration at night and may therefore not be available to interact with a camera rig resting on the sea floor during that time. Diurnal migration patterns are often used by smaller fish to take advantage of lower light and therefore lower chance of being subject to predation while without cover (Beamish, 1966; Strand & Huse, 2007). Further, Strand & Huse (2007) outline reasons that large cod (> 70 cm) might make vertical migrations despite not having many natural predators. They posit that the primary reason large cod were pelagic at night was due to an increased abundance of prey items. This, however, was only observed in situations where there was a lack of benthic prey items and an abundance of pelagic prey items.

4.3.3 Effects of lunar phase on bait interactions

The phases of the moon affect the feeding behavior of fish both directly and indirectly (Battaglia et al., 2022; Lowry et al., 2007; Poisson et al., 2010). Feed intake has been shown to be at its highest in the days leading up to new moon and full moon (Leatherland et al., 1992; Løkkeborg et al., 2012). Kuparinen et.al. (2010) found this phenomenon to also be true regarding freshwater pike. During the lunar phase of “New moon”, significantly more interactions were observed on hooks baited with natural baits than hooks baited with Ecobait for the categories of “Engulf lost” ($p = 0.044$), “Hooked” ($p = 0.042$), and “Engulf total” ($p = 0.004$).

Interactions per hook hour between each bait category were also statistically significant with hooks baited with natural baits for the interactions of “Hooked” ($p = 0.046$), “Engulf total” ($p = 0.0071$), and “Total interactions” ($p = 0.015$) between “New Moon” and “Waning”. While not as pronounced in Ecobait hooks, the general trend remains here as well, though not statistically significant on account of high variance.

One possible explanation for why the interaction rate increased during “New moon” is that the camera rig used for this experiment contained a light source. During “Full moon”, when fish are generally more active too, the moon might reflect enough light that fish are able to navigate and hunt effectively (Afonso et al., 2021). The flashlight attached to the rig might act to draw fish in not only due to the presence of krill (discussed in 4.10) but also so that they were able to observe the baits visually in addition to olfactory cues.

All categories where natural baits experienced significantly more interactions per hook hour than hooks baited with Ecobait were so-called “attack behaviors”. “Engulf lost” and “Hooked” were the only single interaction types to be statistically significant, while the combined category of “Engulf total” was also found to be significant. Perhaps, given that fish are more likely to be out hunting during times where the lunar cycle is in “New” or “Full”, they opt to optimize their time during these phases, given their relatively long separation. During nights where there is either a full moon or a new moon, fish have little time to explore new food sources, and instead resort back to known tastes and textures.

4.3.4 Effects of habitat on bait interactions

Significant differences between the interaction rates of natural baits and Ecobait were observed in a few habitat categories. These were limited to “Engulf spit” in rocky habitats ($p = 0.002$) and “Engulf total” in sandy habitats ($p = 0.018$). Significant effects were only observed in interactions falling in the “Attack” category. This result may be explained by findings indicating that different substrates call for different feeding strategies (Stoner, 2004). Haddock are for instance most often found in habitats consisting of gravel, pebbles, hard clay, and sand (Klein-MacPhee, 2002; Pethon, 2019). They are not often observed in habitats consisting of rocks, kelp, or soft mud (Brodziak, 2005). This is likely due to their feeding strategy, which consists of rummaging through soft substrates in search of slow-moving benthic prey (Løkkeborg et al., 1989). Ling, on the other hand, are often found in habitats consisting of rock and sand, where they hunt fast-moving fish, primarily by eyesight.

Other gadiformes show similar relationship between foraging strategy and habitat preference (Løkkeborg et al., 2000; Pethon, 2019).

In the present study, due to a lack of data, behavior towards bait types were not analyzed with both habitat type and species in the same model. It should be noted, however, that the interaction type “Engulf spit” occurred significantly more often in response to natural baits than Ecobait on rocky habitats, a result mostly caused by ling (see section 3.6). The frequency of “Engulf spit” on hooks baited with natural baits was also significantly higher in rocky habitats than both sandy ($p = 0.0005$) and muddy ($p = 0.0001$) habitats. The possible interaction between species and habitat should be explored further in a larger data set, but it seems likely that this may be caused by the presence of species that are more likely to display this behavior are found in greater abundance on rocky substrates.

4.4 Bait interactions by species

When analyzing data for species separately, haddock and ling were the only species that yielded significant differences for the ratio of interactions for bait types of any category. Haddock and ling accounted for 48.6% and 14.3% of all interactions, respectively. These species also accounted for all statistically significant differences between interaction frequency between natural baits and Ecobait. Haddock were responsible for significant differences in the categories of “Engulf lost” ($p = 0.003$) and “Engulf total” ($p = 0.036$) while ling had significant differences in the categories of “Engulf spit” (0.003), “Hooked” ($p = < 0.0001$), and “Engulf total” ($p = 0.0004$). More pronounced statistical differences were observed with ling, as the highest p-value for ling (0.003) was equal to the lowest p-value found in haddock interactions. As with all “Attack” behaviors, all interactions occurred more frequently with hooks baited with natural baits.

Interactions per hook hour for “Nip” was much higher with haddock than with other species. This accounted for 70% of all interactions with natural baits and 72% of all interactions with Ecobait. The same behavior was observed in Løkkeborg et.al (1989) where it was observed that haddock were more likely to examine a baited hook by displaying multiple nips before a complete engulfment. The reason for this is posited as being due to their feeding strategy in nature, which consists of searching through sand and mud to find slow moving benthic prey. The main prey items for adult haddock are crustaceans, polychaetes, mollusks, echinoderms, and fish (Brodziak, 2005). Further, haddock also have relatively small mouths and are therefore not able to completely engulf prey items in the same way as larger mouthed fishes are. The same fish individual would often nip the same pieces of bait multiple times before swimming off, though this was only counted as one “Nip” unless the fish moved more than one body length away from the hook. This foraging behavior might also be the explanation for haddock displaying significantly more “Engulf lost” interactions. Due to a low sense of urgency in their normal foraging behavior, they might prefer to swim away with their prey and consume it at a later point.

Ling, on the other hand, are large predatory fish that hunt moving prey, primarily by eyesight (Løkkeborg et al., 2000). Similarly, much like the behavior observed in Løkkeborg et.al. (1989) with cod, ling hunt by rapidly striking at their prey with little time to analyze its composition and traits. With the importance of rapidly swallowing the prey item when using this feeding strategy, this may explain why ling were found to have a significantly higher frequency of hookings on natural baits as opposed to Ecobait. This line of thinking does not account for ling being more likely to spit the bait back out when baited with natural baits compared to Ecobait. This may be due to the low number of instances of interactions with Ecobait by ling. Only one instance of “Engulf spit” was recorded with Ecobait as opposed to seven on natural baits.

Interactions with baited hooks by all other species were not statistically significant. For example, whiting accounted for 17.9% of all interactions (and 25.8% of all interactions in the “Nip” category) yet was only observed in one instance on one camera rig and was therefore not statistically significant due to high variation. Other species followed a similar pattern, though not as pronounced, having too few interactions to determine significant differences between their preference towards either natural baits or Ecobait.

4.5 Hooks out of commission

39 baited hooks out of a total of 119 were rendered out of commission during the experiment. This is a bait removal percentage of 32.8%, and divided per bait category, the percentages become 39.3% for natural baits and 27.0% for Ecobait. This further corroborates the findings that fish are more likely to interact with hooks baited with natural baits.

The most common reason for a hook being out of commission with natural baits was due to a fish being hooked and therefore occupying the hook. This accounted for 10 of the 22 removals, or 45.5% of all removals. The next most common occurrence, which accounted for 7 removals, or 31.8%, was due to being removed from the hook by fish. This most often happened during the interactions of “Nip”, or “Engulf lost”. Together, these two causes accounted for 77.2% of bait removals of natural baits. This seems to indicate that natural baits have no systemic issues remaining on the hook and are mostly affected by external stimuli to be removed from the hook.

Ecobait had a lower proportion of hooks in which the bait was removed over the course of a rig set. This may be due to two things – either Ecobait possesses superior traits over natural baits at remaining on the hook, or there were fewer interactions on these hooks, and therefore fewer possibilities for the bait to be removed. The sustained reduced number of interactions on hooks baited with Ecobait seem to indicate the latter as being the main reason for Ecobait’s lower proportion of removed baits. The main two reasons that Ecobait were removed from hooks were due to being removed by fish and due to falling off without any external stimuli, each of which accounted for 29.4% of bait removals. As with natural baits, interactions from fish are a positive indication, but not so if the interaction allows the fish to remove the bait from the hook without becoming hooked in the process. Natural baits and Ecobait had this happen at similar rates. What is not a trait in Ecobait’s favor, however, is the high proportion of baited hooks where the bait fell off the hook with no external stimuli. This was often preceded by a combination of a long soak time and numerous nips and other interactions from fish. Ecobait’s tendency to swell with prolonged soak times and multiple nips and tugs from fish likely weakened its structure to the degree to which it was unable to remain on the hook.

4.6 Method for comparing two bait types

The approach used in this experiment yielded multiple statistically significant differences between bait types. Other experiments trialing manufactured longline bait types have generally been large scale trials, requiring large vessels and many hundreds or thousands of hooks (Henriksen, 2009; Januma et al., 2003; Løkkeborg, 1991). These large-scale experiments also have a lesser degree of direct comparison between the bait types being compared, instead having to rely on aggregated catch rates. With smaller scale experiments, it is much more feasible to bait each hook with alternating bait types. This gives every fish the ability to decide between two bait types and not just those that encounter the longline at the junction between two bait types. Each bait type is also exposed to the same environmental conditions (depth, temperature, habitat) equally. Environmental conditions may vary quite significantly over the length of a typical longline.

The use of video analysis to determine fish ethology provides much more detailed information about their behavior towards baited hooks. It allows for revelations to be made regarding more than just catch rates. An advantage of this for example, is the knowledge that Ecobait sees about as many interactions as natural baits for interactions in the “Exploratory” category, yet consistently sees substantially fewer interactions for those interactions that fall in the “Attack” category. This kind of knowledge gives the researcher great insight as to why or why not a bait behaves a certain way. Is this example, it indicates that the viability of Ecobait as a replacement for traditional longline baits is hampered by its mechanical characteristics rather than its olfactory signature. Another advantage of video analysis is that it shows every fish that both swims by the bait without interacting with any hooks and the fishes that interact with the baits without becoming hooked.

When reviewing video files, it is also possible to accurately determine habitat and environmental conditions more accurately than what may be surmised from a chart or echo sounder. Though not trialed in this experiment, using a camera rig will also open the possibility of attaching other sensors to the metal frame like thermometers, current-, and depth gauges. As observed in this experiment and others, environmental factors have significant impacts on the feeding behavior of fish

(Kasumyan & Døving, 2003; Løkkeborg et al., 1989; Løkkeborg et al., 2014; Stoner, 2004).

The most notable downside of small-scale trials reliant on videos is that it requires much more effort to gather the data than a fishing trial, where most data are collected when the longline is pulled up and the catch rates are recorded. Though this trial was a small-scale trial, with only 251 interactions recorded in total, more than 132 hours of video were reviewed. Using motion tracking software to identify timestamps when fish are in frame is difficult due to the presence of marine snow drifting by the camera lens in periods with current.

Because of smaller datasets, which this method might tend towards, statistical evaluations might not be as sound. To have large enough datasets to make statistical models that yield significance, the models in this trial all had to be constructed with only one factor analyzed at a time. This lessened the degrees of freedom in the model, but limited the conclusions that could be drawn from the results. Incomplete models like this are generally not as reliable as multifactor models yet may have to be employed when sufficient data are not available.

4.7 Methodological considerations

I

The videos analyzed for this experiment were captured at a wide range of depths (8 – 120 m). Since this data point was omitted from a large enough proportion of the data set, the impact of depth could not be taken into consideration for this trial. Were this experiment to be repeated, this would be an interesting data point to compare and see how it may interact with the other factors examined.

II

The speed of the current was also not recorded during this experiment. As outlined in Løkkeborg et.al (2014) and Stoner (2004), current is the main way that odor molecules are spread in water. Therefore, knowing the speed of the current might act as an indicator of how far the odor plume of the different baits was dispersed. This might also be factored into the frequency of observed interactions. If the current were stronger, it might therefore be assumed that one might see a greater number of interactions. On the other hand, this would also mean that any fish interacting during periods of high current would have to swim upstream to reach the odor source. It might be more prudent and a better use of resources to wait for the current to subside before swimming towards the odor source. This would also be in line with observations made by Michaelsen (1988), where cod and haddock were found to spend more time towards the seafloor during periods of low current. With the design of the camera rig being so that it rests on the seafloor, this would be the only place in the water column where observations of fish might be made.

III

The temperature of the seawater was not recorded during this trial. Most fish are ectothermic animals, and their activity level, metabolism, and food intake is therefore partially linked to the temperature of the water around them (Volkoff & Rønnestad, 2020). Though it varies by species, an increase of 10°C may increase the rate of metabolic processes by 2-3 times. Similarly, food intake and food search behaviors increase with temperature, up to a certain point. As rigs were set at both different times of the year and at different depths, it is therefore likely that a range of water temperatures were encountered over the course of this trial. This is likely to have affected behaviors exhibited by the fish, though the degree to which this is the case is unknown.

IV

The full definition for twilight was used for calculations for this experiment. Dawn and dusk are split into three phases, which are related to how far the sun is below the horizon. Civil twilight lasts from the sun dips below the horizon until it reaches 6° below the horizon. During this time, scattered light makes it possible to use vision for most activities. Nautical twilight lasts when the sun is between 6° and 12° below the horizon. There is, however, not enough light that most animals are able to use their vision properly. Astronomical twilight is the period where the center of the sun is between 12° and 18° below the horizon. The level of light during astronomical twilight is low enough that only the dimmest of stars cease to be visible during this twilight phase. Even less light is available for animals not specifically adapted for night vision.

If a more restrictive definition for twilight had been used, different results might have been observed. The most logical place for this more restrictive definition would be to only count observations made during civil twilight. This is the only phase in which there is sufficient light for fish to use their vision for hunting. As outlined in Section 1.4, fish rely on their vision to make informed decisions about whether to attack a prey item.

V

Video analysis conducted during night hours over this experiment often included large swarms of krill (order *Euphausiacea*) attracted by the diving flashlight attached to the camera rig. The fish being observed often preferred to interact with the krill rather than the baited hooks. Krill have been observed to display strong positive phototaxis (Krafft & Krag, 2021; Utne-Palm et al., 2018). Humbrostad et.al. (2018) also suggests how this may affect fish behavior at night, where cod were observed to enter pots illuminated by lights in order to get to the krill swarming around the lights and leading to a 17-fold increase in catch rate compared to unilluminated pots. This is likely the same behavior observed during these night recordings, albeit with different fish species. These fish were more interested in chasing after the krill and would rather leave the baited hooks alone. Using an infrared camera would not solve this issue, as all species involved are ectothermic, and therefore this is seen as an unfortunate downside of using this observation method.

VI

Due to the design of the camera rig used in this experiment, snoods with baited hooks on the ends hung straight down from the main horizontal beam. This is somewhat different to how snoods operate when they are attached to a horizontal longline. In such a case, the longline is apt to rest on the bottom, with the snoods doing the same off to the sides (He, 2021; Nédélec & Prado, 1990). Due to the weight of the camera rig, the descent rate was quite high when set, and so the snoods and hooks experienced quite a bit of turbulence during the descent. This caused the hooks to occasionally become entangled in themselves or the line going up to the surface. This could be somewhat alleviated by threading a silicone tube over the top 15 cm of the snood and fastening it with zip ties, but the problem persisted to some degree afterwards. This problem had two main effects, hooks on the same rig sometimes hung at different distances from to bottom, and even more rarely, hooks became so entangled in themselves that they had little or no slack. The effect to which this impacted interaction rates was not determined. This is not as big of an issue on commercial operations as the descent rate of the longline is substantially lower.

5. Conclusion

In this study, it was determined that a small-scale camera rig setup was able to reveal statistical differences in fish behavior towards baited hooks, when comparing performance of two types of longline bait. Furthermore, utilizing video recordings rather than just catch rates would provide deeper insight into fish ethology when presented with different bait types. This led to the conclusion that a potential new longline bait i.e., Ecobait) showed similar performance to traditional natural baits regarding the response to olfactory cues and other early attack sequence behaviors. The processed bait, however, appeared to lack the necessary traits to make fish display later attack sequence behaviors like strike and swallow.

The approach utilized in this thesis to collect data provided deeper knowledge of fish ethology yet proved to be a time-consuming method to gather data. This caused the available data set to be relatively small. This also led to simpler data processing models having to be used. Further, this study found that numerous environmental factors influence the feeding behavior of fish, in accordance with findings from other publications.

Future studies to examine fish ethology towards baited hooks might employ a similar approach as was used in this experiment. They would benefit from recording more metadata surrounding the trials, as these were missing for some trials during this experiment.

6. References

Adlerstein, S., & Ehrich, S. (2002). Effect of deviations from target speed and of time of day on catch rates of some abundant species under North Sea International Bottom Trawl Survey protocol conditions. *ICES Journal of marine science*, *59*(3), 594-603.

Afonso, A. S., Mourato, B., Hazin, H., & Hazin, F. H. (2021). The effect of light attractor color in pelagic longline fisheries. *Fisheries Research*, *235*, 105822.

Aglen, A., Engås, A., Huse, I., Michalsen, K., & Stensholt, B. (1999). How vertical fish distribution may affect survey results. *ICES Journal of marine science*, *56*(3), 345-360.

Andreoli, V., Bagliani, M., Corsi, A., & Frontuto, V. (2021). Drivers of protein consumption: a cross-country analysis. *Sustainability*, *13*(13), 7399.

Battaglia, P., Pedà, C., Malara, D., Milisenda, G., MacKenzie, B. R., Esposito, V., Consoli, P., Vicchio, T. M., Stipa, M. G., & Pagano, L. (2022). Importance of the lunar cycle on mesopelagic foraging by Atlantic bluefin tuna in the upwelling area of the Strait of Messina (Central Mediterranean Sea). *Animals*, *12*(17), 2261.

Beamish, F. (1966). Vertical migration by demersal fish in the Northwest Atlantic. *Journal of the Fisheries Board of Canada*, *23*(1), 109-139.

Bjordal, Å., & Løkkeborg, S. (1996). *Longlining*. Fishing New Books.

Boopendranath, M., George, V., & Hameed, S. (2009). Fish production and energy requirement during demersal and aimed midwater trawling by intermediate range freezer trawler.

Brodziak, J. K. T. (2005). Essential fish habitat source document. haddock, Melanogrammus aeglefinus, life history and habitat characteristics.

Carr, W. E. S. (1981). *US Patent No. 4245420*.

FAO. (2022). *The State of World Fisheries and Aquaculture*.

Franco, J. M., Bjordal, Å., & Løkkeborg, S. (1987). Synergistic effects of different baits on the same hook in the longline fishery for hake (Merluccius merluccius) and torsk (Brosme brosme).

Gascoigne, J., & Willsteed, E. (2009). Moving Towards Low Impact Fisheries in Europe–Policy Hurdles and Actions. *Seas at Risk. MacAlister Elliot and Partners Ltd. 103pp*, 21-22.

Gjedrem, T., Robinson, N., & Rye, M. (2012). The importance of selective breeding in aquaculture to meet future demands for animal protein: a review. *Aquaculture*, *350*, 117-129.

Grigg, D. (1995). The pattern of world protein consumption. *Geoforum*, *26*(1), 1-17.

Hara, T. (1992). Overview and introduction. *Fish chemoreception*, 1-12.

Hara, T. J. (1994). Olfaction and gustation in fish: an overview. *Acta physiologica scandinavica*, *152*(2), 207-217.

He, P., Chopin, F., Suuronen, P., Ferro, R.S.T and Lansley, J. (2021). *Classification and illustrated definition of fishing gears.*

Henchion, M., Hayes, M., Mullen, A. M., Fenelon, M., & Tiwari, B. (2017). Future protein supply and demand: strategies and factors influencing a sustainable equilibrium. *Foods*, *6*(7), 53.

Henriksen, E. (2009). Det egner seg! Økonomiske effekter av selektivt lineagn. *Nofima rapportserie*.

Humborstad, O.-B., Utne-Palm, A. C., Breen, M., & Løkkeborg, S. (2018). Artificial light in baited pots substantially increases the catch of cod (Gadus morhua) by attracting active bait, krill (Thysanoessa inermis). *ICES Journal of marine science*, *75*(6), 2257-2264.

Januma, S., Miyajima, K., & Abe, T. (2003). Development and comparative test of squid liver artificial bait for tuna longline. *Fisheries science*, *69*(2), 288-292.

Kalmijn, A. J. (1988). Hydrodynamic and acoustic field detection. Sensory biology of aquatic animals,

Kasumyan, A. O., & Døving, K. B. (2003). Taste preferences in fishes. *Fish and fisheries*, *4*(4), 289-347.

Klein-MacPhee, G. (2002). Haddock/Melanogrammus aeglefinus Linnaeus 1758. *Collette, BB, and G. Klein-MacPhee, eds*, 235-245.

Krafft, B. A., & Krag, L. A. (2021). Antarctic krill (Euphausia superba) exhibit positive phototaxis to white LED light. *Polar Biology*, *44*, 483-489.

Kuparinen, A., Klefoth, T., & Arlinghaus, R. (2010). Abiotic and fishing-related correlates of angling catch rates in pike (Esox lucius). *Fisheries Research*, *105*(2), 111-117.

Leatherland, J. F., Farbridge, K. J., & Boujard, T. (1992). Lunar and semi-lunar rhythms in fishes. *Rhythms in fishes*, 83-107.

Leimbach, M., Kriegler, E., Roming, N., & Schwanitz, J. (2017). Future growth patterns of world regions–A GDP scenario approach. *Global Environmental Change*, *42*, 215-225.

Lowry, M., Williams, D., & Metti, Y. (2007). Lunar landings—Relationship between lunar phase and catch rates for an Australian gamefish-tournament fishery. *Fisheries Research*, *88*(1-3), 15-23.

Løkkeborg, S. (1989). *Longline bait: fish behaviour and the influence of attractant release and bait appearance* University of Bergen].

Løkkeborg, S. (1990). Fish shaped bait does not improve the response of coastal cod. *Counc. Meet. Int. Counc. Explor. Sea, CM/B*, *39*(6).

Løkkeborg, S. (1990). Reduced catch of under-sized cod (Gadus morhua) in longlining by using artificial bait. *Canadian Journal of Fisheries and Aquatic Sciences*, *47*(6), 1112-1115.

Løkkeborg, S. (1991). Fishing experiments with an alternative longline bait using surplus fish products. *Fisheries Research*, *12*(1), 43-56.

Løkkeborg, S. (1998). Feeding behaviour of cod, Gadus morhua : activity rhythm and chemically mediated food search. *Animal Behaviour*, *56*, 371-378.

Løkkeborg, S., & Bjordal, Å. (1992). Species and size selectivity in longline fishing: a review. *Fisheries Research*, *13*(3), 311-322.

Løkkeborg, S., Bjordal, Å., & Fernö, A. (1989). Responses of cod (Gadus morhua) and haddock (Melanogrammus aeglefinus) to baited hooks in the natural environment. *Canadian Journal of Fisheries and Aquatic Sciences*, *46*(9), 1478-1483.

Løkkeborg, S., Bogevik, A. S., Humborstad, O.-B., & Palm, A. C. U. (2016). Råstoffkilder for anvendelse som attraktanter i fabrikkert agn.

Løkkeborg, S., Olla, B. L., Pearson, W. H., & Davis, M. W. (1995). Behavioural responses of sablefish, Anoplopoma fimbria, to bait odour. *Journal of Fish Biology*, *46*(1), 142-155. https://doi.org/https://doi.org/10.1111/j.1095-8649.1995.tb05953.x

Løkkeborg, S., Ona, E., Vold, A., & Salthaug, A. (2012). Sounds from seismic air guns: gear-and species-specific effects on catch rates and fish distribution. *Canadian Journal of Fisheries and Aquatic Sciences*, *69*(8), 1278-1291.

Løkkeborg, S., & Pina, T. (1997). Effects of setting time, setting direction and soak time on longline catch rates. *Fisheries Research*, *32*(3), 213-222.

Løkkeborg, S., Siikavuopio, S., Humborstad, O.-B., & Palm, A. C. U. (2013). Kunnskapsbasis for utvikling av alternative lineagn: fiskeatferd, sanseapparat og egenskaper ved agnet.

Løkkeborg, S., Siikavuopio, S. I., Humborstad, O.-B., Utne-Palm, A. C., & Ferter, K. (2014). Towards more efficient longline fisheries: fish feeding behaviour, bait characteristics and development of alternative baits. *Reviews in Fish Biology and Fisheries*, *24*, 985-1003.

Løkkeborg, S., Skajaa, K., & Fernö, A. (2000). Food-search strategy in ling (Molva molva L.): crepuscular activity and use of space. *Journal of Experimental Marine Biology and Ecology*, *247*(2), 195-208.

Michalsen, K., Godø, O. R., & Fernö, A. (1996). Diel variation in the catchability of gadoids and its influence on the reliability of abundance indices. *ICES Journal of marine science*, *53*(2), 389-395.

Montgomery, J., Coombs, S., & Halstead, M. (1995). Biology of the mechanosensory lateral line in fishes. *Reviews in Fish Biology and Fisheries*, *5*, 399-416.

Nédélec, C., & Prado, J. (1990). *Definition and classification of fishing gear categories*. FAO.

Nedreaas, K., Iversen, S., & Kuhnle, G. (2015). Preliminary estimates of total removals by the Norwegian marine fisheries, 1950-2010. *Fisheries Centre Working Paper*, *94*.

Noël, S., Page, E., Chu, E., Sy, E., Brown, C., Cashion, T., Dunstan, D., Frias-Donaghey, M., Hernandez, R., & Popov, S. (2018). Northwestern and Northern Continental Europe: updated catch reconstructions to 2018. *Updating to*, 1950-2010.

Norwegian Mapping Authority. (2021). Tidevannstabell MÅLØY (KINN) 2022. In.

Pauly D., Z. D., Palomares M.L.D. (2020). *Catches by Gear in the Global Ocean*. Sea Around Us. https://www.seaaroundus.org/data/#/global?chart=catch-chart&dimension=gear&measure=tonnage&limit=10

Pethon, P. (2019). *Aschehougs Store Fiskebok, 6th edition*. H. Aschehoug and Co., A/S.

Poisson, F., Gaertner, J.-C., Taquet, M., Durbec, J.-P., & Bigelow, K. (2010). Effects of lunar cycle and fishing operations on longline-caught pelagic fish: fishing performance, capture time, and survival of fish.

Sala, A., Damalas, D., Labanchi, L., Martinsohn, J., Moro, F., Sabatella, R., & Notti, E. (2022). Energy audit and carbon footprint in trawl fisheries. *Scientific Data*, *9*(1). https://doi.org/10.1038/s41597-022-01478-0

Schau, E. M., Ellingsen, H., Endal, A., & Aanondsen, S. A. (2009). Energy consumption in the Norwegian fisheries. *Journal of Cleaner Production*, *17*(3), 325-334.

Sistiaga, M., Herrmann, B., Rindahl, L., & Tatone, I. (2018). Effect of Bait Type and Bait Size on Catch Efficiency in the European Hake Merluccius merluccius Longline Fishery. *Marine and Coastal Fisheries*, *10*(1), 12-23. https://doi.org/https://doi.org/10.1002/mcf2.10007

Sogn-Grundvåg, G., & Hermansen, Ø. (2022). Quality-enhancing fishing in the coastal fishery for Atlantic cod in Norway. *Marine Policy*, *143*, 105191.

Stjerneskinn. (2022). *Soloppgang, solnedgang og skumring for Måløy i 2022*. Retrieved March 6, 2023 from https://stjerneskinn.com/soloppgang-maaloey.htm

Stoner, A. W. (2004). Effects of environmental variables on fish feeding ecology: implications for the performance of baited fishing gear and stock assessment. *Journal of Fish Biology*, *65*(6), 1445-1471. https://doi.org/https://doi.org/10.1111/j.0022-1112.2004.00593.x

Strand, E., & Huse, G. (2007). Vertical migration in adult Atlantic cod (Gadus morhua). *Canadian Journal of Fisheries and Aquatic Sciences*, *64*(12), 1747-1760.

Time and Date. (2022). *Månefaser 2022 i Måløy, Norge*. Retrieved March 14, 2023 from https://www.timeanddate.no/astronomi/maanefaser/norge/maloy?aar=2022

United Nations. (2022). *World Population Prospects 2022*.

Utne-Palm, A. C., Breen, M., Løkkeborg, S., & Humborstad, O. B. (2018). Behavioural responses of krill and cod to artificial light in laboratory experiments. *PloS one*, *13*(1), e0190918.

Volkoff, H., & Rønnestad, I. (2020). Effects of temperature on feeding and digestive processes in fish. *Temperature*, *7*(4), 307-320.

Ward, P., Myers, R. A., & Blanchard, W. (2004). Fish lost at sea: the effect of soak time on pelagic longline catches.

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