Converting Fish Waste to Fish Bait in California Trap Fisheries

Griffin Garner

Master of Advanced Studies Candidate
Marine Biodiversity and Conservation
Scripps Institution of Oceanography
University of California, San Diego

Capstone Advisory Committee:

DocuSigned by:
Dave Rudie
E3CE6723CF784F6...

Dave Rudie
Committee Chair
President
Catalina Offshore Products

DocuSigned by:
Sarah Mesnick
2C1BA18C2CD142D...

Dr. Sarah Mesnick
Committee Member
NOAA Southwest Fisheries Science Center
Scripps Institution of Oceanography, UCSD

DocuSigned by:
Mark Helvey
B79E4796D92F40B...

Mark Helvey
Committee Member
Sustainable Seafood Consultants
NOAA Fisheries (retired)

DocuSigned by:
Ross Talner
5BAFB93965DC4E1...

Ross Talner
Committee Member
Facility Manager
Catalina Offshore Products

ABSTRACT
Moving towards full utilization and a zero waste seafood industry requires creative and cost effective solutions. For trap fisheries, such as lobster and crab, large quantities of bait are required by each vessel to capture the targeted species. Fish waste products leaving seafood processing plants can be utilized to help meet the demand for bait. This pilot project seeks to investigate bait use in three California trap fisheries: spiny lobster, Dungeness crab and rock crab, to create an experimental bait product utilizing fish waste to benefit processors, fishers, and the environment. The initial waste-to-bait products were field tested in each fishery, with catch results compared to the traditional baits used by commercial trap fishers. The preliminary results were encouraging and suggest that his approach could create a revenue stream, reduce the burden of expensive bait for fishers, and help the industry move towards full utilization and zero waste.

INTRODUCTION

When most people think of bait, images of worms on a line or a small bait and tackle shop come to mind. An often overlooked, yet integral part of fishing, bait can consist of many different species or objects and is used in many forms of fishing worldwide. Longlining, trolling, trap, and hook and line fishing all use bait to catch target species. When determining the sustainability of a fishery the focus has traditionally been on the catch, not the bait, resulting in limited bait-based research. For common bait species like sardines, anchovies, and mackerel, these foraging fish play a crucial role as a food source that supports entire ocean ecosystems.[1] These fish are also in high demand for direct human consumption and aquaculture feed, and juggling these demands can put strain on limited resource fisheries.

This capstone project focuses on California trap fisheries for crab and lobster. These are high value fisheries with a low environmental footprint, landing locally-sourced high quality protein, and supporting a vibrant local fishing community.[2] In fact, Dungeness crab is the most valuable fishery in California with an ex-vessel value of 52 million dollars in 2021.[3] The trap fishing industry uses millions of pounds of bait each season yet there is limited information on which baits are used and their efficacy in landing targeted species. This project seeks to investigate the use of fish waste as bait, with the ultimate goal of increasing both ecological and economic sustainability by repurposing fish waste from seafood processors to meet bait demand, reduce waste, and provide a potentially more cost-effective solution.

[1] Kaplan, I. C., Koehn, L. E., Hodgson, E. E., Marshall, K. N., & Essington, T. E. (2017). Modeling food web effects of low sardine and anchovy abundance in the California Current. *Ecological Modeling*, *359*, 1-24.
[2] California Department of Fish & Wildlife (CDFW). (2021). California Commercial Landings for 2021, Table 15
[3] California Department of Fish & Wildlife (CDFW). (2021). California Commercial Landings for 2021, Table 15

Background:
Trap fisheries in California set baited traps to catch target species. The type of bait utilized varies by region, fishery, and the preferences of individual fisherman. This project will focus on three commercial trap fisheries: California spiny lobster *(Panulirus interruptus)*, Dungeness crab *(Metacarcinus magister)* and rock crab (*Cancer productus)*. These three fisheries were chosen based on geographic location, timing of the fishing season, high bait use, and high landing values. All three fisheries are managed under the California Department of Fish and Wildlife (CDFW).

California Spiny Lobster:
In California, the commercial spiny lobster fishery extends from San Diego to Point Conception with landing values of 15 million dollars[4]. The commercial season runs from October 6th to March 16th. Fishers are allowed to fish up to 300 traps during the season from October to March and the traps must be serviced at least every 96 hours.[5] Each trap is baited, and refreshed about twice per week each time fishers haul their traps. For a typical fishing season, this translates to about 40 bait changes per trap, and for a fisher with 300 active traps, resulting in roughly 12,000 bait changes throughout the season. There are 186 active permits in the fishery, and if each permit used all 300 traps for the season, the fishery would require 2,232,000 bait changes, or over 2 million pounds of bait.[6][7] This number can vary greatly because early in the season fishers are checking and pulling their traps daily when the catch volume is the highest and most consistent. Later in the season the traps are checked less frequently when the catch volume is the lowest. This represents a significant volume of bait being utilized earlier in the season, while bait demand drops similarly to the drop in catch volume.

This project focuses on the commercial lobster fishery in San Diego. Fishing is typically within 5 miles of shore and completed on day trips, although some fishers will travel to Cortez Bank or other locations offshore. The depth can be as shallow as 6 feet up to around 200 feet depending on the time in the season and weather. Fishers set individual traps with buoys in "lines" that are usually at set depths. Common places for setting traps in lines are at the borders of marine protected areas around La Jolla. The most common baits for lobster fishing are salmon heads and mackerel. Fishers also utilize fish carcasses from local seafood processors. Fishers will seek out their favorite baits at the beginning of the season when daily catch is the highest, and then utilize cheaper bait options like seafood by-products from processing later in the season when daily catch is lower.

California Dungeness Crab:
Dungeness crab is the largest trap fishery in California and spans from Santa Barbara to Crescent City at the Oregon border. with landings estimated at 52 million dollars for 2021.[8][9] This is a

[4] California Department of Fish & Wildlife (CDFW). (2021). California Commercial Landings for 2021, Table 15
[5] Shiao, A. (2016). *California Spiny Lobster Fishery Management Plan. 239.*
[6] NOAA. (2020). *California Spiny Lobster Fishery—MMPA List of Fisheries | NOAA Fisheries* (West Coast). https://www.fisheries.noaa.gov/national/marine-mammal-protection/california-spiny-lobster-fishery-mmpa-list-fisheries
[7] Poindexter, O. (2020) Bait Feasibility Analysis
[8] Voices of the Bay (2011) *Fisheries basics- California fisheries: Dungeness crab ~* http://sanctuaries.noaa.gov/education/voicesofthebay.html
[9] California Department of Fish & Wildlife (CDFW). (2021). California Commercial Landings for 2021, Table 15

limited entry fishery with 600 total permits.[10] The 2021-2022 season started on December 29th and ran until April 20th, which is a shortened season due to whale entanglements.[11] Fishing takes place both in State and Federal waters usually within 50 miles of shore at depths from 60-300 feet.

This project focused on Dungeness fisheries in central and northern California. Dungeness crab fishers in Fort Bragg, for example, routinely travel three and a half hours each way to get out to the crabbing grounds. Fishers typically set 100-200 pots but larger vessels may set 1500 pots.[12] Approximately 80% of landings are made in the first month of fishing.[13] Most fishers utilize circular pots that are 3 to 3.5 feet in diameter and weigh 60-120 pounds.[14] Fishers place individual pots in lines or "strings", which have one starter buoy and one end marker buoy, and the pots are not attached together.[15] Strings can be a mile long and have anywhere from 10-60 pots. Boat size ranges from small boats that fish day trips to larger boats that can stay out for weeks. Dungeness crab fishing is highly dependent on the weather, so fishers fish when they can, usually 1-2 times per week. Fishing practices vary regionally and individually with fishers using a variety of different bait types like squid, mackerel, sardines, clams, and fish carcasses from seafood processors.

Rock Crab:
Commercial rock crab fishing takes place throughout all of California and is open year round, with landing values of xxxx. This is the smallest trap fishery out of the three discussed, with only a small number of rock crab fishers in San Diego. Rock crab fishers fish close to shore from Point Loma to La Jolla. The depth is usually 100-250 feet. Fishing is done on day trips, usually taking half a day. Fishing occurs once per week where the traps are baited and set, and then pulled the next week. Fishers place pots in strings with a starter and end buoy, with 3-7 pots, and the pots are all connected . Pots are usually spaced 150-200 feet apart and strings are typically set around 0.8 miles from each other. The strings can be set closer or farther apart if the fisher prefers or the circumstances require such change. Rock crab fishers are the least selective for baits and fishing practices out of the three trap fisheries in this project. They can obtain fish carcasses from processors, sport fishing boats, and friends. Fishing is dictated by when fishers can get bait, usually for free, to make fishing efforts economical.

---

[10] Voices of the Bay (2011) *Fisheries basics- California fisheries: Dungeness crab ~* http://sanctuaries.noaa.gov/education/voicesofthebay.html
[11] CDFW News. *(2022). CDFW Moves Quickly to Close the Commercial Dungeness Crab Fishery Statewide in Response to Humpback Whale Entanglements*
https://wildlife.ca.gov/News/cdfw-moves-quickly-to-close-the-commercial-dungeness-crab-fishery-statewide-in-response-to-humpback-whale-entanglements
[12] Voices of the Bay (2011) *Fisheries basics- California fisheries: Dungeness crab ~* http://sanctuaries.noaa.gov/education/voicesofthebay.html
[13] Dewees, Christopher & Sortais, Kristen & Krachey, Matthew & Hackett, Steven & Hankin, David. (2004). *Racing for crab. Costs and management options evaluated in Dungeness crab fishery.* California Agriculture. 58. 186-189. 10.3733/ca.v058n04p186.
[14] *Oregon coastal zone fishery management analysis*. (1979).
https://www.govinfo.gov/content/pkg/CZIC-sh328-o7-1979/html/CZIC-sh328-o7-1979.htm
[15]NOAA, CDWF. (2021). *Best Practices Guide for minimizing marine life entanglement*
https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=195428&inline

Bait Prices for Trap Fishers:
Fishers utilize a diversity of baits with prices ranging from free up to $5.50 per pound. Fishers expressed that the high price for some bait can be worth it, leading to higher catch rates of target species. However, the price of bait is one of the more expensive and limiting aspects of day to day fishing for trap fishers in California. Fishers are constantly exploring and seeking out the cheapest possible prices for bait. This project is important because it aims to create a bait product that may reduce the burden of expensive bait and add convenience and efficiency to the fisher's day, all while utilizing an overlooked resource to close a part of the loop in the seafood food system of San Diego.

Seafood Processors:
Seafood processors buy seafood products from fishers and process it for distribution locally, nationally, and internationally. When fileting fish, processors are often left with large quantities of organic material -- seafood by-products with currently limited outlets for secondary utilization. Seafood processors such as Catalina Offshore Products (COP), one of the largest in San Diego, are left with fish scraps including skin, bones and heads after each day of work. For example, COP can produce anywhere from 4,500-20,000 pounds of by-products from processing each week depending on the season, weather and fishing efforts.[16] Currently, COP provides fishery by-products to an organic farmer for conversion to fertilizer and compost and to lobster fishers for bait, with little to waste going into the trash..COP seeks uses for secondary utilization of its fish waste, but the limited outlets and high volume of waste make it challenging to achieve full utilization. This research project is a collaboration with COP to develop and test ways of converting fish waste to bait and to evaluate the costs and value of the bait product to COP as well as the desirability of the products by the fishers who rely on it. If successful, COP could integrate this system into daily operations, and this process could be scaled with different seafood processors in San Diego and beyond, which similarly are confronted by large amounts of by-product which cannot go into landfills.[17]

Research Questions:
The project pairs the production of fish waste from seafood processors with the need for bait from commercial fishers, with the goal of developing and testing a waste-to-bait product for California trap fisheries. Ultimately, the goal is to increase the economic and ecological sustainability of California fisheries while reducing waste and increasing value. Specifically, there are the following five objectives:

1. Review current bait practices in CA trap fisheries.
2. Review current fishery byproduct disposal practices in CA seafood processors.
3. Create a sample product in collaboration with Catalina Offshore Products COP.
4. Field test samples in three commercial trap fisheries: spiny lobster, Dungeness crab, and rock crab.
5. Develop a plan for future bait testing in both commercial and recreational trap fisheries.

[16] Personal communication with Thomas Mejia. (April 20th, 2022). Receiving/ QA Manager, Catalina Offshore products
[17] *SB 1383: State Organics Law – RethinkWaste*. (2022.). https://rethinkwaste.org/businesses/laws-ordinances/sb-1383-state-organics-law/

METHODS

1. Review of current bait practices in CA trap fisheries

The first step in this project was to observe current baiting practices in three California trap fisheries: spiny lobster, Dungeness crab and rock crab. Observations were conducted from January 2021 to June 2022. Data was collected through informal conversations with processors and fishers, and fishing trips with multiple fishermen in each fishery. Information on what bait species were used, the bait form, and timing in the season for use were collected for each fishery. Information on bait prices and where the fishers sourced their bait was also collected.

2. Review of current practices in California seafood processors

Processors in Southern, Central and Northern California were evaluated for this project. Six seafood processors in San Diego were evaluated in May to learn more about their fish waste and determine if there was an opportunity to expand the project to new processors. This review was part of a larger effort to evaluate waste streams in San Diego. Catalina Offshore Products was the main processor collaborating on this project and was used as a case study to learn how this project could be implemented into daily operations. In March and April, two trips were made up to Central and Northern California, visiting a total of nine seafood processors in Morro Bay, Santa Cruz, Halfmoon Bay, San Francisco, and Fort Bragg. These two trips had the same goals of learning about current practices for processors and learning how fish waste was dealt with in areas of California with large seafood processing ports. Through processor tours and informal conversations, data was collected on how much fish waste was being produced, where the waste was ending up, and if it was being utilized for bait or other secondary-use opportunities.

3. Sample product production

The first step in creating a sample bait product was to determine the best form and method of delivery. Through conversations with processors and trap fishers, it was ultimately decided that creating a ground-up bait product had the most potential to maximize benefits for both the processor and the fishers. After settling on a product form, product development, delivery and testing followed. Potential grinders were researched based on price, ability to grind up fish, and the feasibility of buying and setting up. Delivery method of the bait was decided through testing trials and conversations with fishers on what they would like to receive based on their current practices. All ground bait development was conducted at COP.

4. Field test samples

After three trap fisheries and fishers willing to participate were identified, experimental design was carried out to determine the best methods for testing baits and collecting data. A fishing license, commercial permits, and crewmember licenses were purchased for each fishery in order to follow California Department of Fish and Game (CDFW) regulations as well as allow the researcher to work as a deckhand. When possible, I was onboard for pulling and checking traps, and data on the bait and haul was collected in a data book. If it was not possible for me to be present, data was collected by fishers through CDFW logbooks and photos of hauled traps.

Spiny Lobster:

- Fished with three lobster fishers in San Diego
- Three field tests of experimental bait
- Data was also collected on usability (ex. was it easy to use, did fishers like it, would they use it in the future)

Rock Crab:

- Fished with two rock crab fishers in San Diego
- One field test of experimental bait
- Data was also collected on usability (ex. was it easy to use, did fishers like it, would they use it in the future)

Dungeness Crab:

- Worked with one Dungeness crab fisher in Fort Bragg, CA
- Three field tests of experimental bait
- Data was also collected on usability (such as ease of use, desirability, and interest in future use)

6. Develop a plan for future bait testing in both commercial and recreational trap fisheries

Using the knowledge gained from research, field testing, and interactions with commercial fishers and processors, future testing plans were developed in order to assess the potential for increased scale or or other forms of utilization. This is further explored in the Discussion.

RESULTS

1. Bait Practices

Baiting practices vary by fishery and individual fisher preferences (Table 1). Dungeness crab fishers utilize the most species of bait and baiting devices, followed by lobster fishers, and lastly rock crab fishers. Baiting methods can also vary throughout the duration of the fishing season. Some fishers utilize more bait species and baiting methods not covered in Table 1.

Table 1. Review of current bait practices in CA trap fisheries

Fishery	Baits	Baiting Practices
Spiny Lobster (San Diego) Season: October 6th - March 16th (San Diego-Santa Barbara)	-Salmon heads -Mackerel -Bonita -Fish carcasses from processing	The two most used baits in San Diego are salmon heads and mackerel. The 12 lobster fishers who sell to COP used 92,162.45 pounds of salmon heads and 18,149.00 pounds of mackerel this season.[18] Typically fishers put 1-4 pounds of bait in each trap, but this depends on the type of bait. Baits are placed in a center bait compartment. A typical baiting might be two salmon heads, one salmon head and a mackerel, or one salmon head with fish scraps/carcasses. Carcasses from processors are typically used

[18] Personal communication with Thomas Mejia (April 20th, 2022), Receiving/ QA Manager, Catalina Offshore products

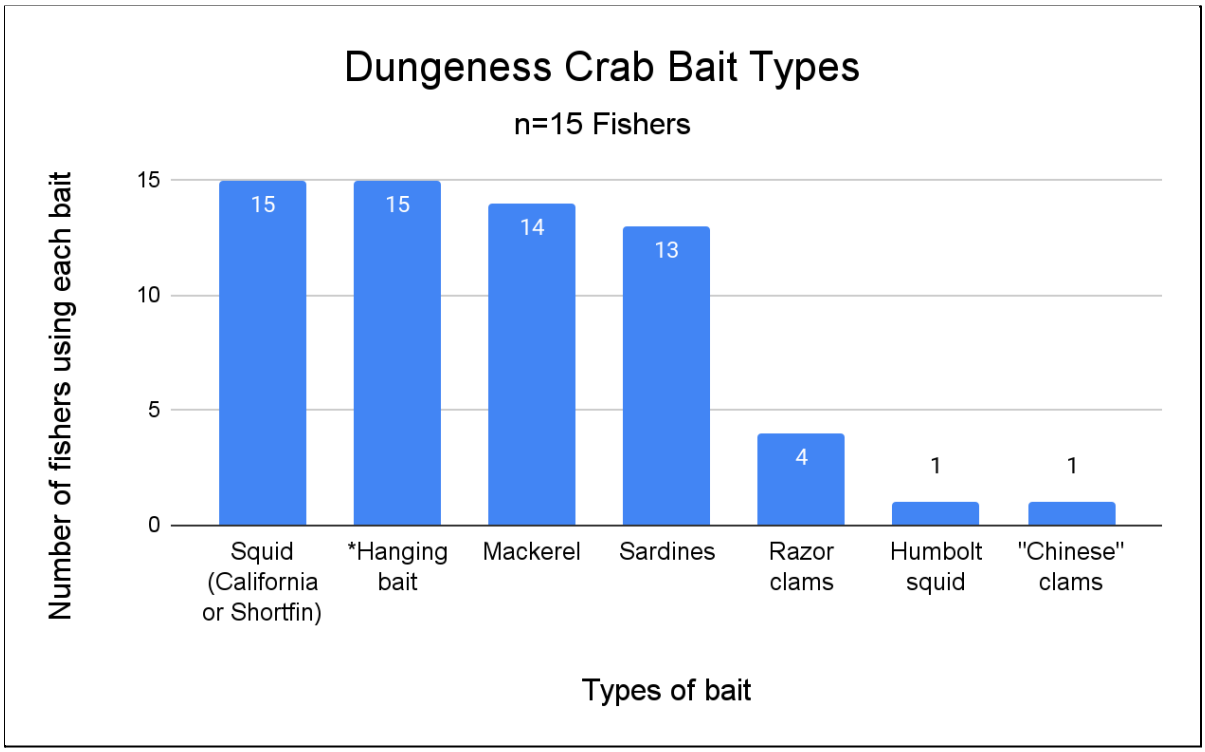
Source: n=7 San Diego fishers		as filler bait and are not the most desired baits. These less desired baits become very important in the second half of the season, when the daily catch volume starts to fall off and fishers need the cheapest baits possible. Bait bags and cups are usually used on longer and deeper soaks. although one fisher put all of their baits into bait bags before setting.
Dungeness Crab (Central and Northern California) **Season:** December 29th - April 20th (Santa Barbara-Crescent City) *early closure from whale entanglements **Source:** n=15 fishers -Morro Bay -Santa Cruz -Halfmoon Bay -San Francisco -Fort Bragg	-California squid -Shortfin squid -Humboldt squid -Mackerel -Sardines -Razor clams -Chinese clams -Fish carcasses from processing	Fishers utilize different methods for containing bait in their traps:bait cups, jugs, bags, and jars depending on the bait and soak times. The most common baits are squid, mackerel, and sardines and are typically chopped up and put into bait cups. Carcasses from processors usually get put in rope mesh bags and clipped to the top of the trap so they are hanging. Some larger vessels have hydraulic bait grinders on board in order to chop baits before placing it in cups. Smaller vessels usually have a hand chopper to break down baits for cups. Razor clams seemed to be the favorite bait by far, but the high price precludes fishers from using them more. Half of a clam can be placed in a small glass jar with holes, potentially producing favorable results for over a week.
Rock Crab (San Diego) **Season:** year round (Whole state) **Source:** n=4 fishers in San Diego	-fish carcasses, heads, and scraps/bloodline from processing	The least amount of bait types and baiting devices were used in this fishery. Fishers utilize fish carcasses from processors, sport fishing boats, and friends for bait. Traps either have a centralized bait compartment like lobster traps or the baits are just placed into the open traps. Tuna was the most commonly used bait during field observations. Whole tuna heads and frames were placed into traps. A typical baiting might be 3 small tuna heads, 1 large tuna head, and 4 yellow tail heads. Fishers typically leave the traps to soak for a week.

Dungeness crab bait types:

Fishers used about 2 to 2.5 lbs of bait per trap and a variety of bait types and delivery systems (Figure 1). All fishers used squid and hanging bait, which are typically fish carcasses in chewy bags. Fishers also often mix bait within the traps and will use different baiting methods like chewy bags or scotty cups for baits that have different soak times. For example, squid might fish for 30 hours, while razor clams would last for 72 hours. Fishers would not want to put these baits

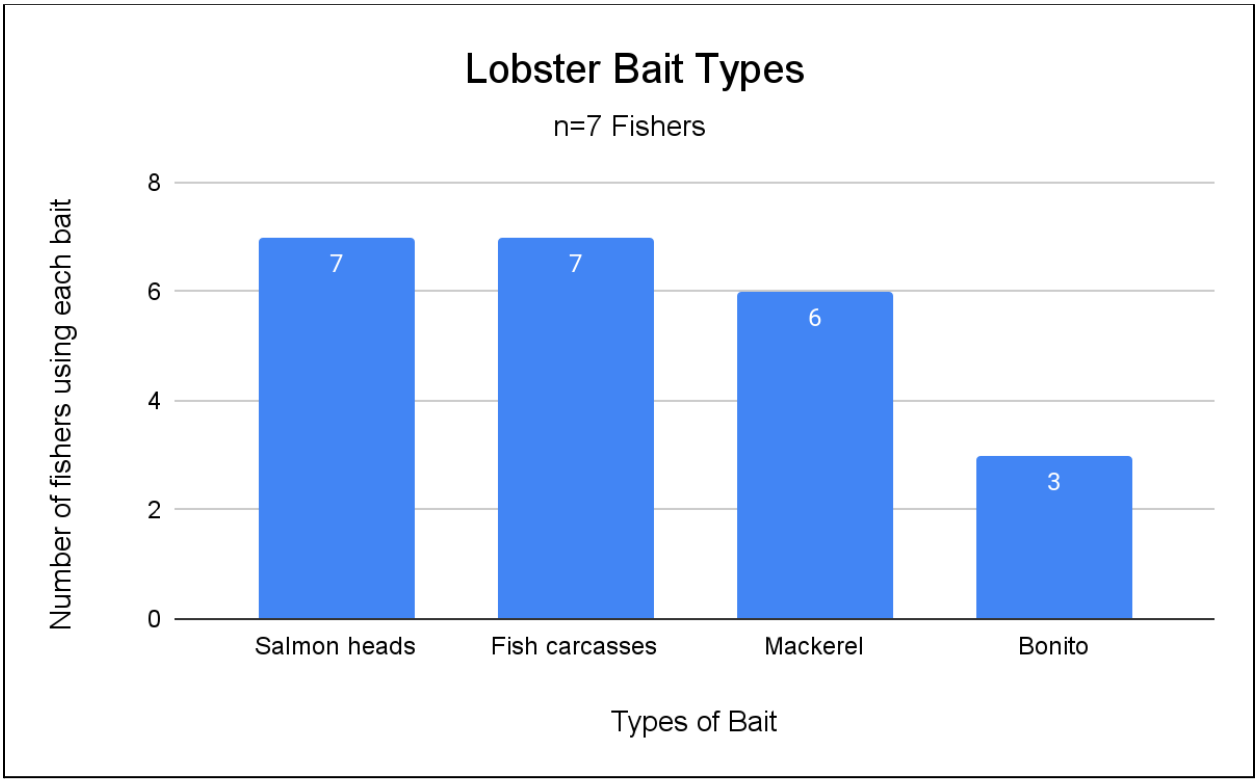
together in the same bait cup because the bait that fishers for less time may spoil the bait with a longer soak time. Fishers also used different types of bait over the season, depending on availability and cost. Data was collected from a week-long trip to Central and Northern California and conversations with 15 fishers. Figure 1 does not represent how much of each bait type is utilized, just the different types used throughout the season.

Figure 1. Summary of Dungeness crab bait types



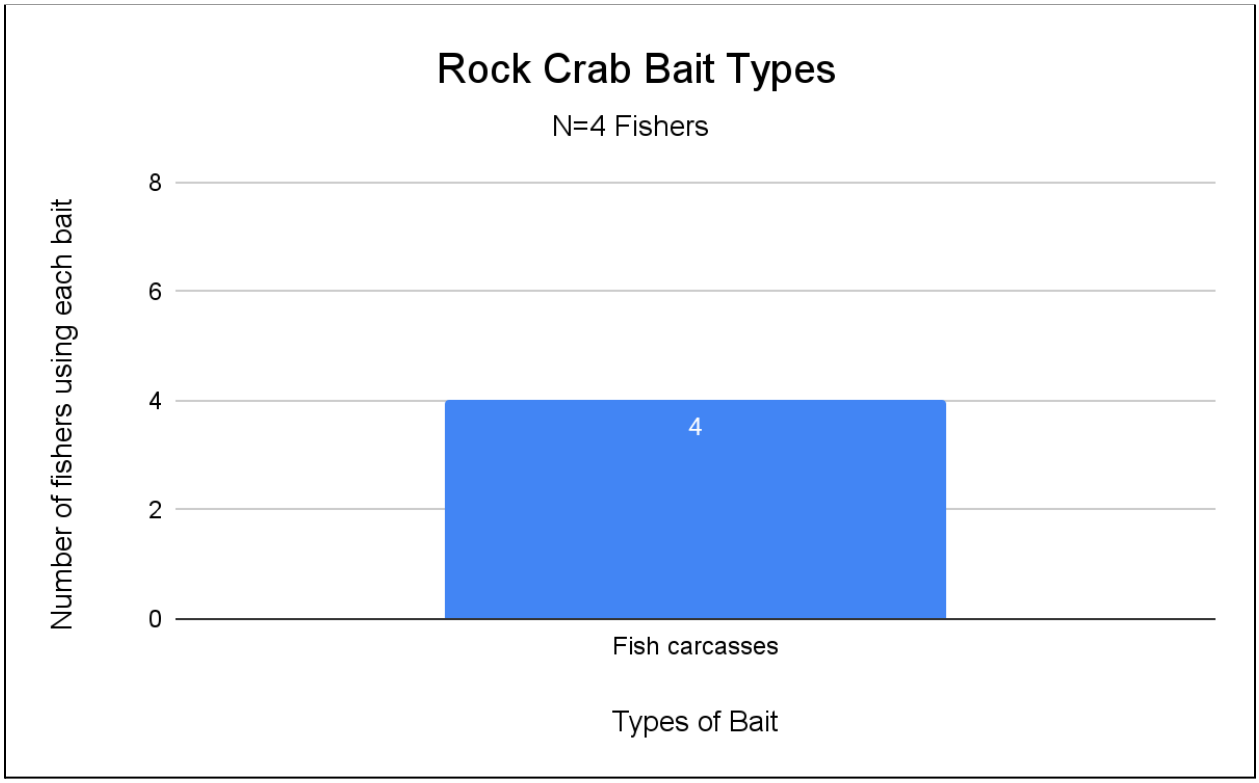
Lobster fishery bait types:
All 7 lobster fishers used salmon and fish carcasses (Figure 2). Fishers will use different baits throughout the season. Typically the best producing baits will be prioritized during the start of the season, when fishers are catching the majority of their lobsters. During the last couple of months of the season, fishers will prioritize the cheapest bait options that they can find, (usually fish carcasses from processors and recreational fishing boats). Baits are put directly into the bait compartment of the lobster traps. Data was collected from December - March 2022 and the sample size was 7 fishers. Figure 2 does not represent how much of each bait type is utilized, just which types are used during the season.

Figure 2. Summary of Lobster bait types



Rock crab bait types:
All 4 rock crab fishers use the same bait, fish carcasses from processors and recreational fishing vessels (Figure 3). The most common fish carcasses observed were various tuna species and yellowtail. Rock crab fishers often utilize longer soak times so they will "bait heavy", adding multiple fish carcasses and heads to the trap. One rock crab fisher explained that he fishes when he can get bait from his bait source channels, so the bait determines when he will fish, which is different from the lobster and Dungeness crab fisheries. Data was collected from April - May 2022 and the sample size was 4 fishers. Figure 3 does not represent how much of each bait type is utilized, just which types are used during the season.

Figure 3. Summary of Rock crab fishers using each type of bait.

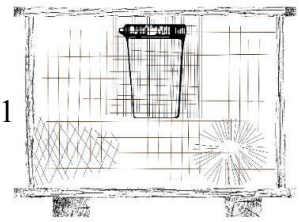


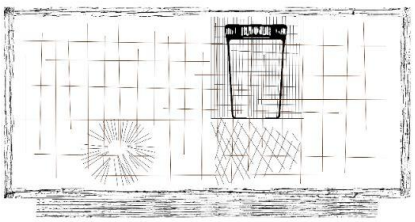
Schematics of commercial traps with bait:
The following diagrams illustrate the design of the traps. Traps 1, 2, 3, and 4 are baited lobster traps. Trap 3 (2 salmon heads) was the most common baiting option that was observed. Trap 5, 6, 7, and 8 are baited Dungeness crab pots. Trap 8 (1 bait cup and a chewy bag filled with carcasses) was the most common baiting option observed. Most Dungeness crab baits are clipped to the trap with a bait pin or zip ties so they are hanging inside the trap. Bait cups or "scotty cups" are used both in the lobster and Dungeness crab fisheries and have small holes that allow scent to escape attracting lobster and crabs. "Chewy" bags are open rope or mesh bags that allow the crabs to eat or "chew" on the baits in the bags.

Figure 4. Common trap baitings for lobster and Dungeness crab. Drawings: Alejandro Cato (MAS MBC 21' Alumni)

Lobster traps:

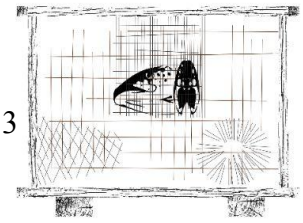
Trap 1

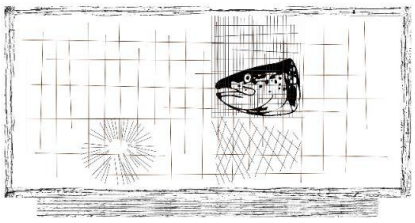




Trap 2

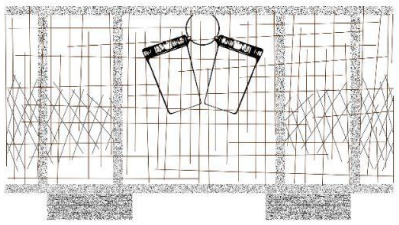
Trap 3





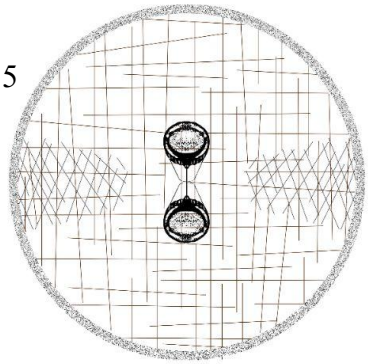
Trap 4

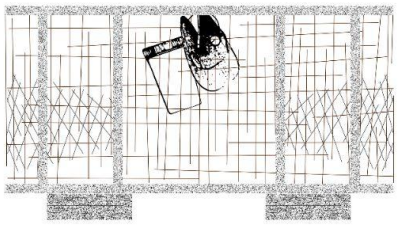
Dungeness crab traps:



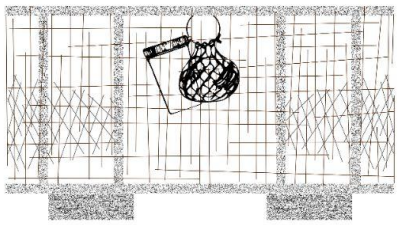
Trap 6

Trap 5





Trap 7



Trap 8

Bait costs:
Bait prices can vary depending on the species and the fishery. Prices ranged from free to $5.50 per pound. Fishers seek out the cheapest bait options and use partnerships, fishing cooperatives, and processor arrangements to locate them.

Table 1. Bait prices

Lobster Bait - Price/Pound[19]

Bait	Price for Fishers
Salmon heads	$0.60 for fishers selling product to the processor ~$1.00 for other fishers
Mackerel	$0.75 for COP fishers ~ $1.25 for non-COP fishers
Bonito	~ $0.85
Fish Carcasses	Currently free or ~$0.10

Dungeness Crab Bait - Price/Pound[20]

Bait	Price for Fishers
California squid	~ $2.15
Shortfin squid	~ $1.40
Humboldt squid	unknown
Mackerel	~ $1.50
Sardines	~ $1.20
Razor clams	~ $5.50
“Chinese” clams	~ $2.20
Fish carcasses	Currently free or up to $0.06

Rock Crab Bait- Price/Pound[21]

[19]Personal communication with 7 lobster fishers (December-March 2022)
[20] Personal communication with 15 Dungeness crab fishers (March-May 2022)
[21] Personal communication with 4 rock crab fishers (April-June 2022)

Bait	Price for Fishers
Fish Carcassses	Free*

*Fishers have agreements with processors and recreational fishing boats to acquire "free" bait, but usually provide something in return or make other arrangements.

2. Processor practices

Seafood processors in California utilize a variety of methods to dispose of fish waste (Table 2). Processors look for alternatives to trash collection pickup because it can be costly depending on how much fish waste is being produced, or in some cases, there may not be a trash collection service available to collect seafood byproducts. Processors that sell lobster and crab usually have relationships with fishers who sell the product, in exchange for free bait, or bait at a reduced price. SB 1383, a new organic waste law for California, will make the process of disposing organic waste (seafood waste by-products) more challenging for processors, forcing more accountability and transparency.[22] The majority of processors in this study expressed the need for increased utilization of seafood byproducts in California, as some processors were producing up to 20,000 pounds per week depending on the season, weather, and fishing catch rates with minimal outlets for use.[23]

Table 2. Review of current practices in California processors

San Diego Processors:

Number of processors	Fish waste disposal practices	Seafood by-product uses	Biggest challenges
6	● Trash collection service (can be expensive) ● Giving to farmers (free) ● Selling to pet food companies (Jaemar) for $0.6 a pound. Jaemar provides separate sanitary bins	● Bait for trap fisheries (1 processor wanted .25¢ per pound) ● Farming ● Edible scraps + cuts for sale (bellies, collars, heads, cheeks, spoon meat) ● Leather + jewelry ● Petfood	● The cost of trash collection service ● SB 1383 (California organic waste disposal law) ● Separating usable fish waste from trash ● Storage for fish waste (large carcasses requiere large bins)

[22] *SB 1383: State Organics Law – RethinkWaste*. (2022.). https://rethinkwaste.org/businesses/laws-ordinances/sb-1383-state-organics-law/

[23] Personal communication with Thomas Mejia (April 20th, 2022), Receiving Manager, Catalina Offshore products

	for fish.		• Electricity costs required to refrigerate/freeze waste

Northern California Processors

Number of processors	Fish Waste Disposal Practices	Seafood Waste Uses	Biggest Challenges
9	• Trash collection service (expensive or not available for some locations) • Selling to Agrothrive (a liquid organic fertilizer company) • Dumping off the docks • Giving to farmers (free)	• Bait for trap fisheries • Farming • Edible scraps + cuts for sale (collars, cheeks, bellies) • Sea urchin shells for roads • Aquaculture feed	• The cost of trash pick up • In Morro Bay, there was no trash collection service and processors were not provided with adequate size disposal bins • SB 1383 (California Organic waste disposal law) • Storage for fish waste

Seafood processors in California utilize a variety of methods to dispose of fish waste. Processors look for alternatives to trash collection pickup because it can be costly depending on how much fish waste is being produced, or in some cases, there may not be a trash collection service available to collect seafood byproducts. Processors that sell lobster and crab usually have relationships with fishers who sell the product, in exchange for free bait, or bait at a reduced price. SB 1383, a new organic waste law for California, will make the process of disposing organic waste (seafood waste by-products) more challenging for processors, forcing more accountability and transparency.[24] The majority of processors in this study expressed the need for increased utilization of seafood byproducts in California, as some processors were producing up to 20,000 pounds per week depending on the season, weather, and fishing catch rates with minimal outlets for use.[25]

3. Sample Product Production

[24] *SB 1383: State Organics Law – RethinkWaste*. (2022). https://rethinkwaste.org/businesses/laws-ordinances/sb-1383-state-organics-law/

[25] Personal communication with Thomas Mejia (April 20th, 2022), Receiving Manager, Catalina Offshore products

Trials with the woodchipper:
The woodchipper chosen was not designed for grinding fish so modifications were necessary. For the first several tests, carcasses were fed into the chipper through the main hopper, the largest space that could fit whole, large carcasses like halibut, white seabass, yellowtail and grouper. For this method, the large shoot led into the main compartment of the chipper, where spinning hammers beat down the material. This method of grinding fish was used for the initial bait testing with the lobster fishery, although it was clear that the volume of ground fish needed to be produced could not be accommodated and the consistency of the mix was more sludge-like than uniformly chopped.

The woodchipper also has a smaller side shoot that was designed to break down small branches. The shoot fed into the main compartment and was met with a spinning blade that was hidden until further inspections were made to the inside of the chipper. We decided to try the side shoot out with some small carcasses and to our disbelief, it worked. Instead of having the chipper beat down the carrcasses, this new method chopped up the carcasses. The raw material coming out of the chipper was more consistent in size, and we were able to break down fish much faster, although this method limited the size of carcasses able to process. See figure 5 for a photo of the wood chipper.

Figure 5. Roto hoe woodchipper

Product forms produced:
Three methods of delivery were chosen based on input from fishers: 5 gallon buckets, prepackaged bait cups, and 30-50 pound frozen blocks (Figure 6-8). All three product forms differed in opportunity, constraints, and feedback from fishers (Table 3). The easiest form to produce was 5 gallon buckets, as the raw ground up material could be placed directly into the buckets and then given to the fishers right away. The hardest form to produce was the prepackaged bait cups as more time and labor was required to pre-stuff the cups and then the cups had to be loaded into the freezer. The most requested form was prepackaged bait cups, which eliminates the time and labor required for fishers to stuff their traditional baits into bait

cups on the boat before baiting and setting traps. The 30-50 pound frozen blocks allow fishers to receive large quantities of the ground up bait, if they are after quantity over ease of use.

Figure 6: 5 gallon buckets

Figure 7: Pre-packaged bait cups

Figure 8: 30-50 lb blocks

Table 3. Sample product forms- opportunity, constraints, and feedback from fishers

Product form	Opportunity	Constraints	Usability feedback from fishers
5 gallon bucket (fresh or refrigerated) tested in: spiny lobster fishery	Easy to produce, ground fish can go straight into buckets. Less labor is required and lowers the cost to produce without the need to freeze. Fishers can buy as many buckets as they need and then return the old ones, to get them filled.	This would only be applicable for lobster season or in another fishery where fishers were buying bait every day or every couple days. Hard to work with for fishers operating a vessel by themselves, this form requires deckhands to stuff it in bait containers.	Good feedback from lobster fishermen, easy to work with when fresh, and easy to grab a handful to stuff into bait cups. Fishers liked that the bait took up less space on the boat than the typical large trash bins that fill the deck, (usually 3-6 bins). Again only feasible for a fishing operation of more than one person, (need a deckhand)
Prepackaged bait cups (frozen)	Easy for the fishers to use. The bait cups can	More labor and time required to produce. If	This was the most requested bait product

tested in: rock crab fishery	be put straight into the traps. Ideal for fisheries that utilize bait cups like Dungeness crab and Lobster.	freezing, the cost of electricity and storage space. Price of bait cups and lids. Might be less bang for their buck for bait for the fishers.	form, especially by the deckhands who were charged with baiting. Can save a lot of time to fill traps with bait. Can make the work environment safer on the deck so deckhands don't have to use blades and knives to cut and chop bait. For rock crab testing, the fisher thought that the bait cups needed larger holes to help with water flow and scent dispersion as the bait seemed to clog the holes on the pull when checking traps.
30-50 pound blocks (frozen) tested in: Dungeness crab fishery	Great way to send ground bait in bulk (we shipped 150 pounds up to Fort Bragg). Similar to the 5 gallon buckets, easy to produce, raw material goes straight into boxes lined with plastic into the freezer.	The blocks need to be frozen so the cost of electricity and storage could be high. Bulky and heavy to move around. Could take a couple of days to fully thaw out to a slushy consistency that's easy to work with.	This form was the hardest for fishers to work with since the blocks were large, heavy, and took a long time to fully thaw. Since the mix of ground fish has bones, spines, and fins, it can be dangerous to cut and work with when the bait is frozen. Deemed “shit bait” by Princess seafood Dungeness crab crew members, it was not their favorite bait to say the least. However, after the blocks fully thawed out, the crew actually liked working with the bait a lot more and it was easy to fill bait cups by hand.

Fish parts tested:
A variety of different fish parts were tested during the bait production process (Table 4). The easiest parts to grind up were the bloodlines and filet trimmings as there were usually no bones. Skins of different fish and of different sizes were tested but unable to be ground up with the chipper. The most limiting factor on the ability to grind up different fish parts was the size of each piece. Large heads, carcasses, fins, and bones would either not fit into the chipper or were too thick to break down.

Table 4. Ability to grind up different fish parts

Parts of fish	Ability to grind up (yes, no, depends on size)	Comments
Whole carasses	Depends on size	
Skins	No	The skins were tough and would come out as whole pieces.
Heads	Depends on size	If the head could not fit through the wood chipper point of entry, it was not possible.
Fins	Depends on size	Large, thick tail fins from fish like grouper, halibut, and white seabass were not possible to grind up.
Filet trimmings/bloodline	Yes	
Guts	Yes	
Bones	Depends on size	Large bones from yellowtail, tuna, and white seabass were not possible to grind up and would stall the motor of the wood chipper.

Fish species tested:
Table 5 represents data collected from trying to grind different species through the wood chipper. In total, 13 different types of fish were tested. The biggest limiting factor for grinding up whole carcasses was the size in relation to the point of entry for the wood chipper. If the carcass was too large to fit, it was not possible to be ground up. Small carcasses from fish like snapper, rockfish, sculpin, and salmon were the easiest to grind up because of the overall size and thickness of the bones and fins.

Table 5. Ability to grind up different fish

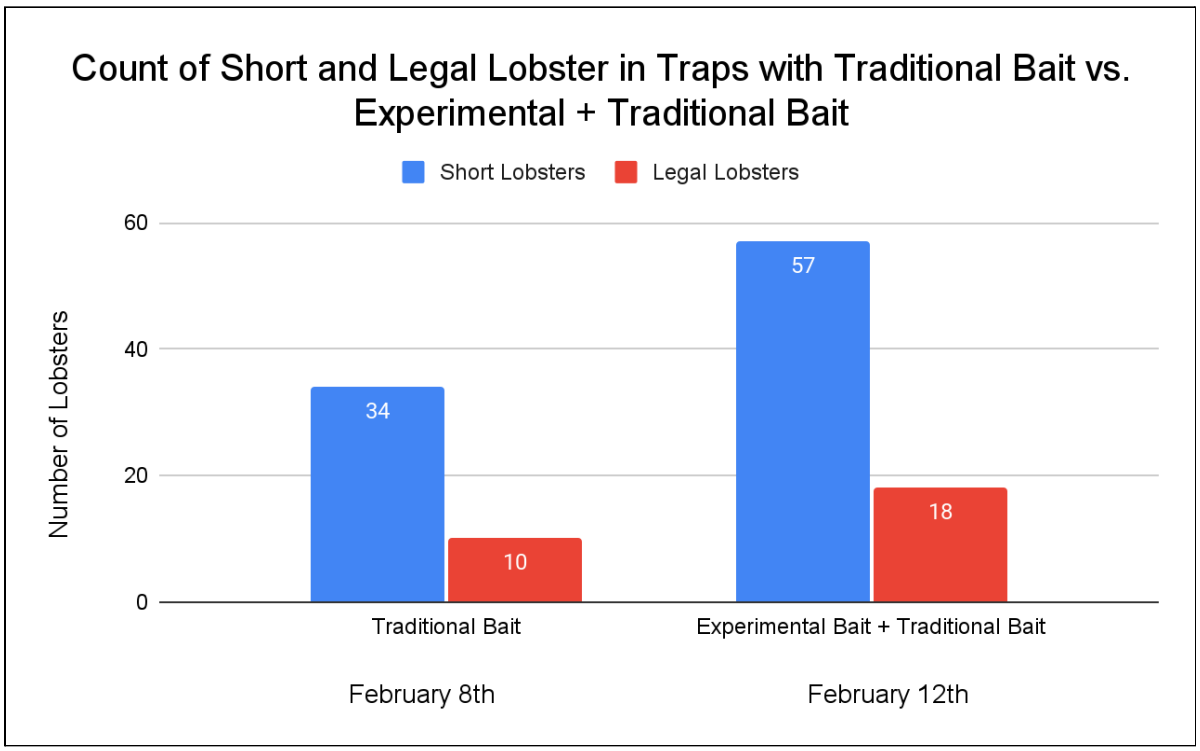
Fish Tested	Ability to Grind up (yes, no, depends on size)	Comments
Salmon	Yes	N/A
Rockfish	Yes	N/A
Yellowtail	Depends on size	Small to medium size yellowtails worked, large yellowtail frames did not fit into the wood chipper
Halibut	Depends on size	Small to medium size halibut worked, large halibut frames did not fit into the wood chipper
Tunas	Depends on size	Bonito, albacore, and skipjack worked. Whole yellowfin and bluefin frames did not.
Snappers	Yes	N/A
Sculpin	Yes	N/A
Sheephead	Yes	N/A
Blakcod	Yes	N/A
Grouper	Depends on size	Small to medium size grouper worked, large grouper frames did not fit into the wood chipper
Swordfish	No	N/A
Pompano	Yes	N/A
Striped bass	Yes	N/A

4. **Field Testing**

Spiny lobster:

Figure 9 shows the results of 2 different days pulling traps with normal bait on February 8th (N=50 traps) and pulling traps with a mix of different baits, some traps with just experimental bait in bait cups, some traps with experimental bait in bait bags, and the rest of the traps with experimental bait in bait cups and normal bait (1-2 salmon heads) on February 12th (N=55 traps). On February 12th, 5 more traps were used for testing and some of the traps had (experimental + traditional bait) so these traps had more bait then the traps set on February 8th, with just traditional bait.

Figure 9. Total number of legal and short lobsters caught with traditional bait (February 8th, n=50 traps) and a mix of experimental and traditional bait



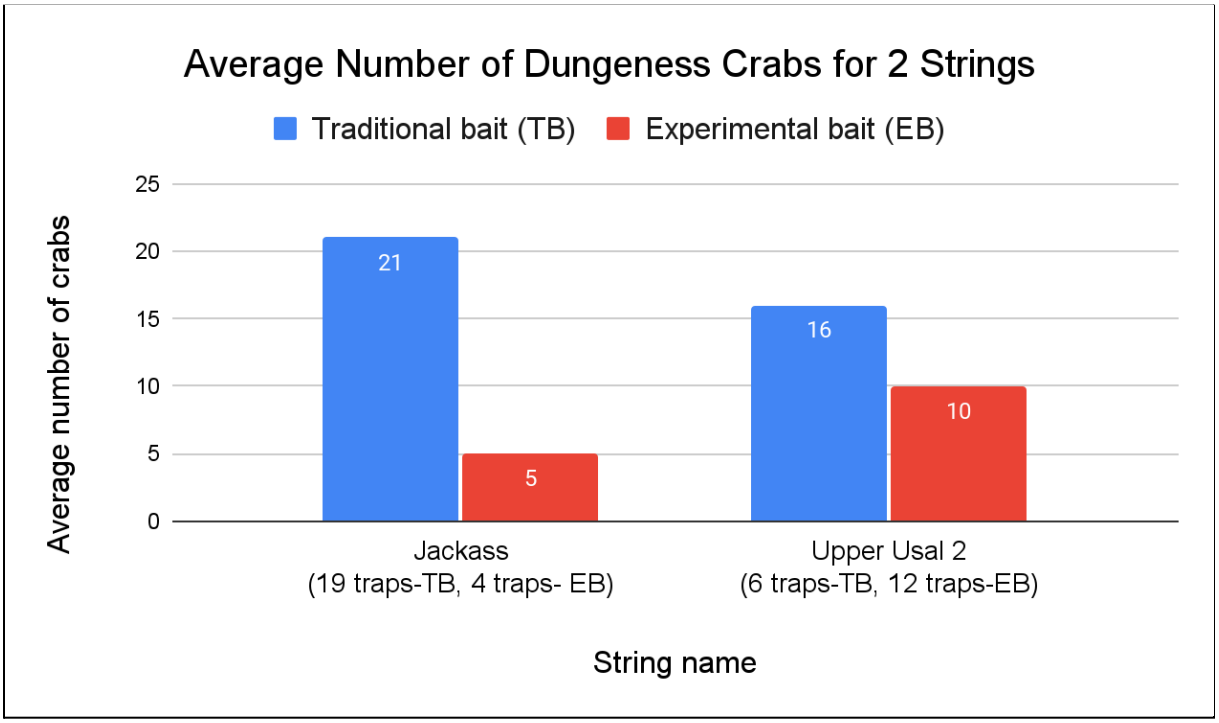
Field testing results for the lobster fishery were collected through CDWF commercial logbooks where fisher's record legal and short lobsters. The traditional bait caught 34 short lobsters and 10 legal lobsters for a total of 44. The mix of traps with experimental bait in cups and bait bags, as well as the traps with a mix of experimental bait and traditional bait caught 57 short lobsters and 18 legal lobsters. The researcher was unable to go out fishing to record the lobster catch data, which would have provided catch results by trap and by string.

Dungeness Crab:

Total crab counts were collected from photos taken of each pot on each string as the pots came up onto the boat (Figure 10). The “Jackass string” had 19 pots with traditional bait (squid in bait cup or jug + carcasses in chewy bag) and 4 pots with experimental bait (1 bait cup or jug with ground fish) and had a soak time of 4 days before pulling. Upper Usal 2 had 6 pots with traditional bait (squid in bait cup or jug + carcasses in a chewy bag) and 12 pots with experimental bait (2 bait cups filled with ground fish) and had a soak time of 7 days before pulling.

For the Jackass string, the traditional bait caught an average of 21 crabs per trap and the experimental bait caught an average of 5 crabs per trap. The jackass string is the fisher's best producing string each season. For the Upper usal 2 string, the traditional bait caught an average of 16 crabs per trap while the experimental bait caught an average of 10 crabs per trap.

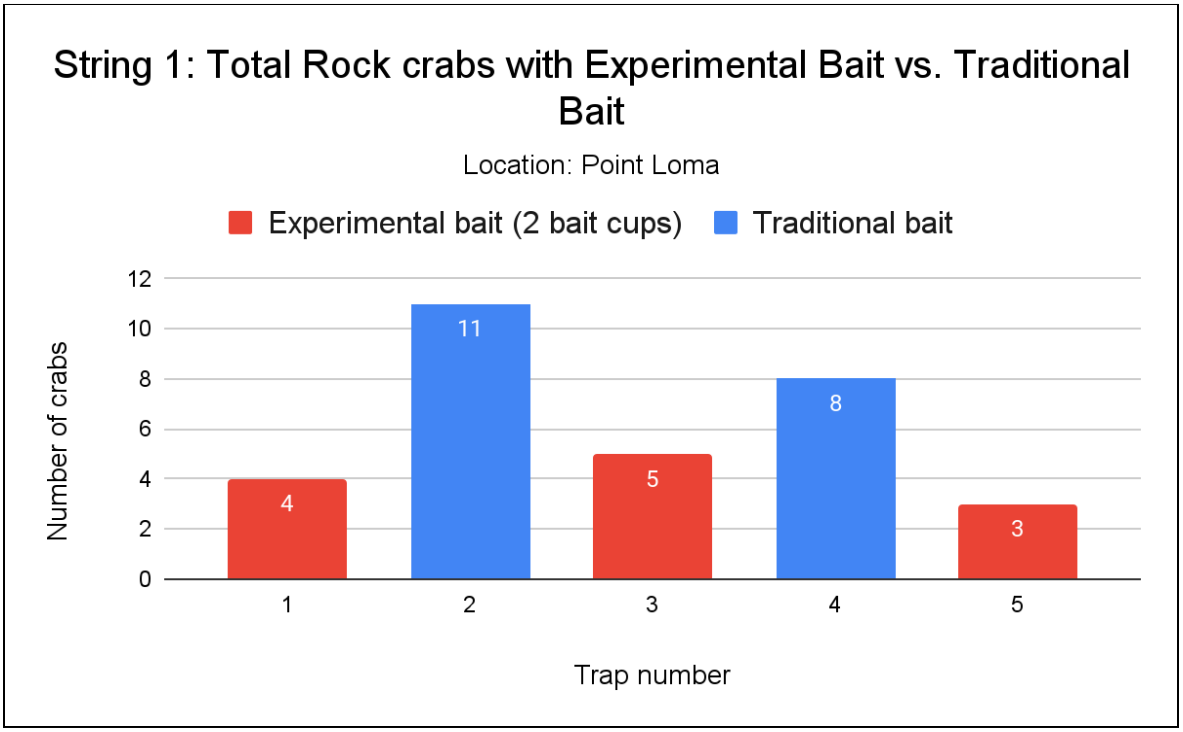
Figure 10. Average number of Dungeness crabs for 2 strings comparing traditional and experiment bait



Rock Crab:

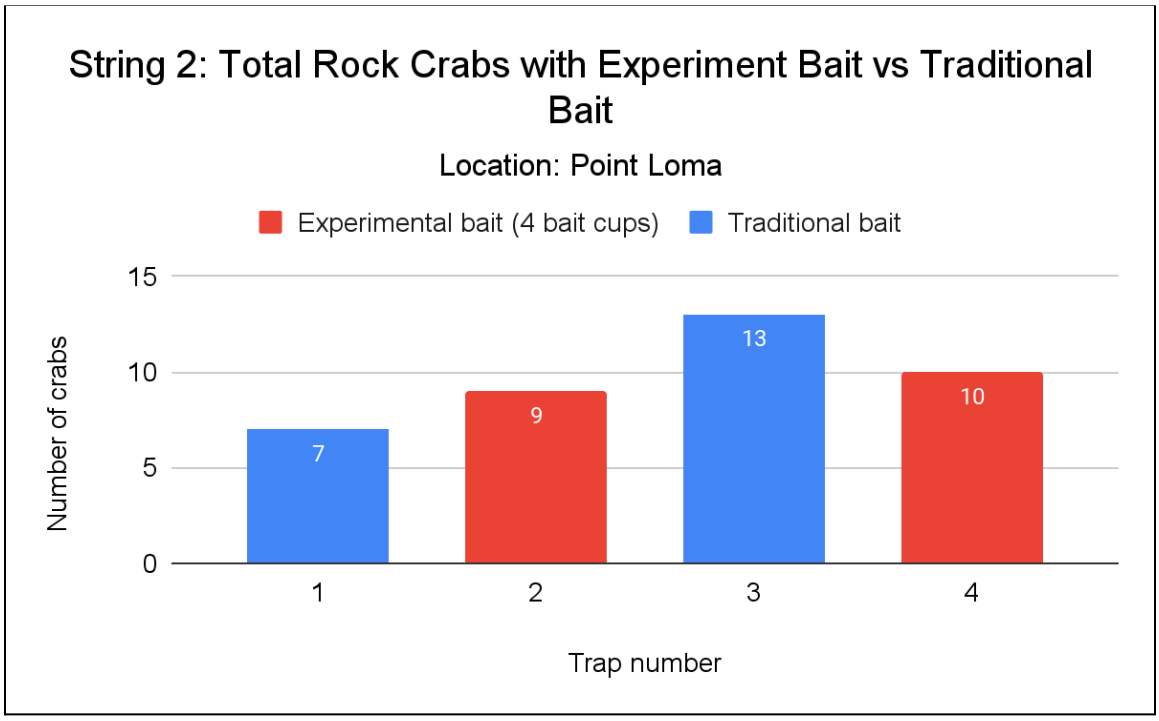
Total crab counts were collected by the researcher out on the boat when pulling in traps (Figure 11). This string had 5 traps: 3 traps with experimental bait, which was 2 bait cups per trap, and 2 traps with traditional bait, which was multiple tuna or yellowtail carcasses/heads. The string was set off of Point Loma in 150 feet of water. The traditional bait caught 11 and 8 crabs. The experimental bait caught 4, 5, and 3 crabs for the traps.

Figure 11. Total rock crabs per trap with experimental and traditional bait for string 1



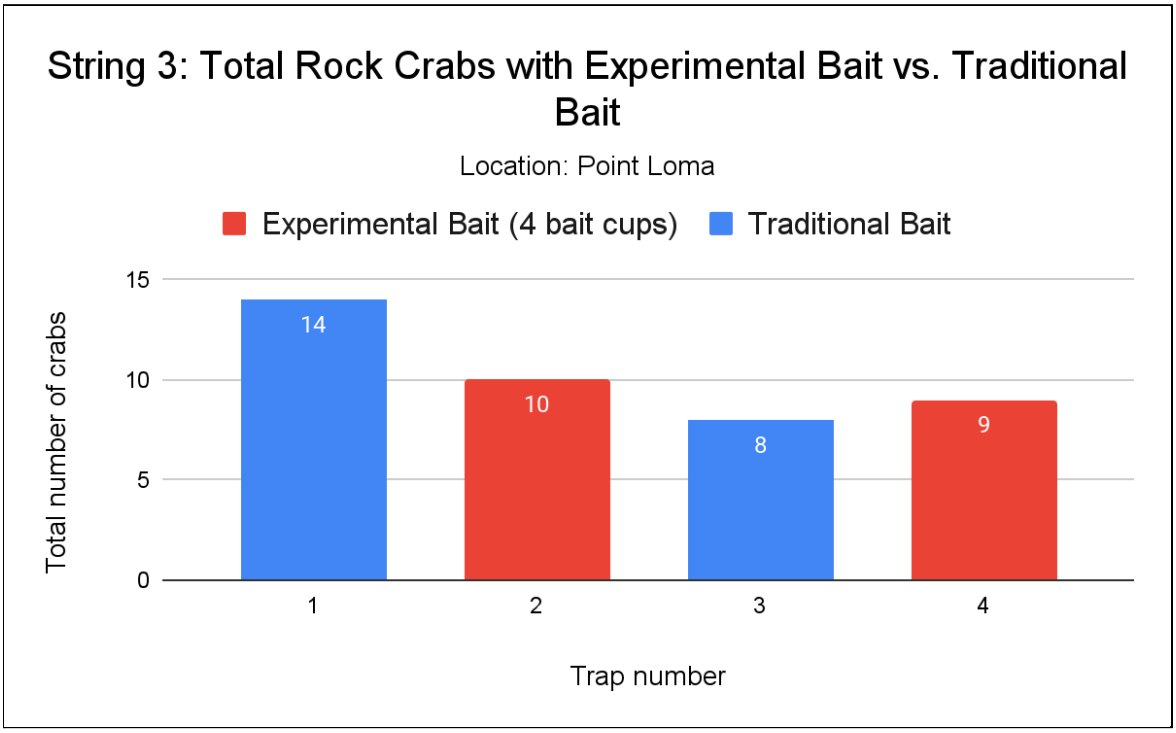
Total crab counts were collected by the researcher out on the boat when pulling in traps. This string had 4 traps: 2 traps with experimental bait, which was 4 bait cups per trap, and 2 traps with traditional bait, which was multiple tuna or yellowtail carcasses/heads. The string was set off of Point Loma in 160 feet of water. The traditional bait caught 7 and 13 crabs. The experimental bait caught 9 and 10 crabs for the traps.

Figure 12. Total rock crabs per trap with experimental and traditional bait for string 1



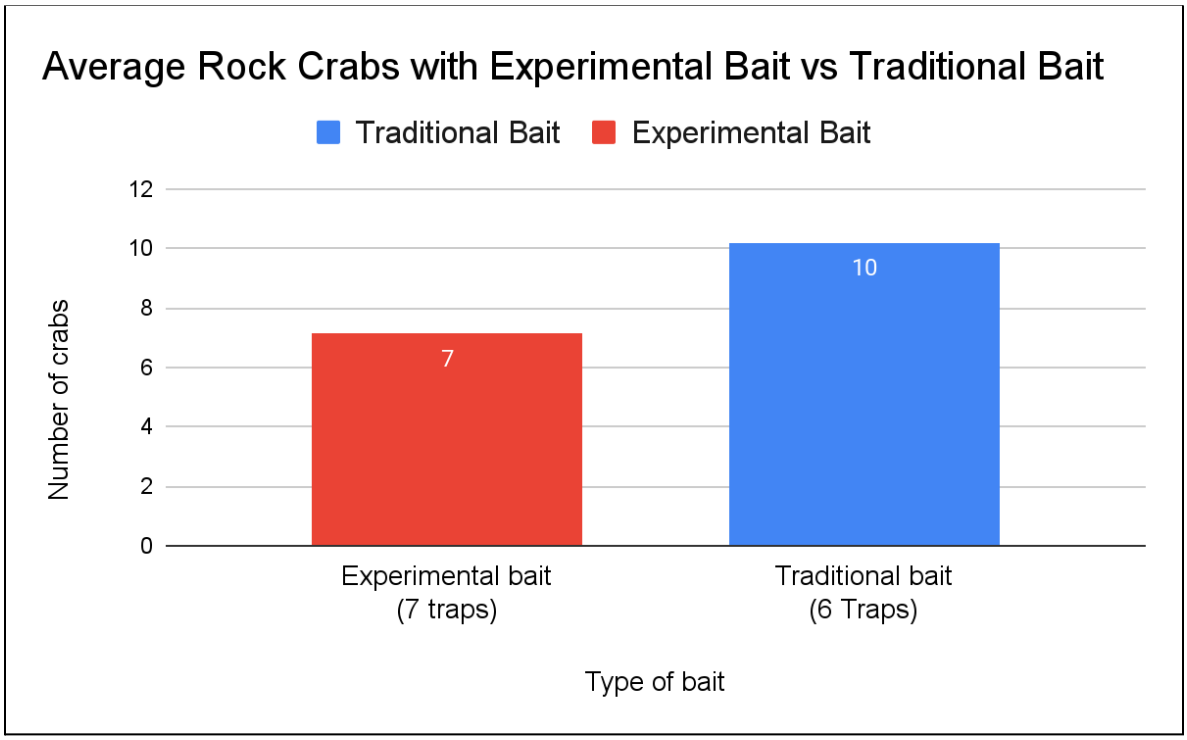
Total crab counts were collected by the researcher out on the boat when pulling in traps. This string had 4 traps: 2 traps with experimental bait, which was 4 bait cups per trap, and 2 traps with traditional bait, which was multiple tuna or yellowtail carcasses/heads. The string was set off of Point Loma in 150 feet of water. The traditional bait caught 14 and 8 crabs. The experimental bait caught 10 and 9 crabs for the traps.

Figure 13. Total rock crabs caught per trap with experimental bait and traditional bait for string 3



The average number of crabs caught with experimental bait and traditional bait was found using the catch data for the 3 strings. For the rock crab field testing, in total 7 traps had experimental bait and 6 traps had traditional bait. The experimental bait caught an average of 7 crabs per trap, and the traditional bait caught an average of 10 crabs per trap.

Figure 14. Average rock crabs for experimental bait and traditional bait for all 3 strings



Data on rock crab catch results were collected by the researcher out on the boat. One field test was completed with 3 strings. The experimental bait caught the highest number of crabs in strings 2 and 3. Both of these strings used 4 bait cups per trap for the traps with experimental bait, while string 1 used only two bait cups per trap for the traps with experimental bait. For each string, the traditional bait produced a higher number of crabs than the experimental bait. All three strings were set off of Point Loma in depths ranging from 150-160 feet and were placed around 0.8 miles apart.

DISCUSSION

This project set out to investigate bait use in three commercial trap fisheries and to create waste-to-bait products utilizing fish waste to benefit processors, fishers, and the environment. The bait practices of each fishery were identified, revealing what species were used, when, and in what delivery form. The Dungeness crab fishery had the most variation in bait species and baiting devices used. It's important to understand that fishers utilize many different types of bait over the course of the fishing season and will seek out the cheapest possible baits. However, at the start of each fishing season, fishers will use their preferred baits to take advantage of high catch rates to capitalize on fishing efforts. In the later stages of the fishing season, fishers will use more "filler" bait, utilizing more fish carcasses from processing. The rock crab fishers in San Diego that collaborated on this project exclusively use fish carcasses from processors and recreational charter fishing boats. The lobster fishery in San Diego does utilize fish carcasses, but mainly in the second half of the fishing season when salmon heads and mackerel become too expensive for fishing efforts to be economical.

Fish processors in San Diego and Central and Northern California expressed interest in this project and constantly seek out outlets for secondary utilization of their seafood byproducts. In San Diego, fish processors used a variety of different services and methods to dispose of seafood byproducts. Processors struggle with the cost of trash collection services and prefer to be paid by a service or company to pick up their waste. Pet food companies often pay processors for their waste, however this can be more time consuming for processors as it is necessary to separate waste into separate, sanitized bins. Seafood by-product uses can vary by region, and processors seek out local, specific uses for the location. An example is using sea urchin by-products to stabilize dirt roads in Northern California.

Producing the experimental baits was challenging and one of the biggest obstacles for completing this project. Since this was a pilot project with limited funding, we had to search for the most cost effective method for grinding up fish waste at COP. Industrial size grinders can easily cost over 10,000 dollars, making it necessary to explore smaller and cheaper options.[26]A video of fishers using wood chippers to make chum or "burley" in New Zealand provided insight on what direction to look in.[27] The woodchipper was the most cost effective option for this project. A Roto Hoe wood chipper was purchased for $175 and it fulfilled its purpose of grinding up fish for the waste-to-bait products. Using a wood chipper to grind up fish carcasses on a larger scale would not be feasible for future waste-to-a bait projects, but investment in a larger processing machine may be economical depending on the scale of future research.

Throughout the waste-to-bait product development process, we worked closely with the fishers. It was important to include fishers in all steps of the project as this project was inspired by fishers, for fishers. This level of collaboration was imperative to create a product that fishers would ultimately want to use. Through fisheries observations and informal conservations with fishermen and processors, three delivery forms were developed for testing: 5 gallon buckets,

---

[26] JWC Environmental. (2022.). *30K & 40K In-line Muffin Monster*. https://www.jwce.com/product/30k-40k-inline-muffin-monster/

[27] Ultimate Fishing.(2014). *The Ultimate Burley Trail! YouTube*. https://www.youtube.com/watch?v=Mp6Dt9RI6eg

30-50 pound frozen blocks, and pre-packaged bait cups. All three product forms differed in opportunity and constraints for execution. The easiest form to produce was 5 gallon buckets, as the raw ground up material could be placed directly into the buckets and then given to the fishers right away. The hardest form to produce was the prepackaged bait cups as more time and labor was required to pre-stuff the cups and then load them into the freezer. The most requested form was prepackaged bait cups, as it eliminates the time and labor required for fishers to stuff their traditional baits into bait cups on the boat before baiting and setting traps. The 30-50 pound frozen blocks allow fishers to receive large quantities of the ground up bait, if they are after quantity over ease of use as the frozen blocks require several days to thaw. However, after thawing a certain amount, fishers in Fort Bragg were receptive to the frozen blocks.

In order to make grinding up all fish carcasses straight from the cutting line feasible, processors would need a large, industrial size grinder with a large shoot size to fit all sizes of fish bought and processed, such as large tunas, swordfish, grouper, and opah. This operation would require the least amount of additional labor to make this process feasible so that the processor can cut down on expenses wherever possible. Processors have large totes or bins where most fish carcasses, scraps, and bones are placed after being cut. By grinding up the fish waste, processors can cut down on the amount of storage space needed to keep the bait in refrigerators or freezers which in turn leads to lower electricity and storage costs. Grinding up the fish waste can also create a non species specific product that can be used as a universal bait for multiple different fisheries. With this method, one can still select a certain desirable species to grind up, or one can throw a variety of different species into the grinder. Once the fish waste is put through a grinder, the processor is left with raw product that can be used for multiple different purposes. The ground up fish could be used as bait, farm fertilizer, sold to pet food companies, or used as fish meal for aquaculture.

For the fishers, having ground up bait ready for use in the traps is very beneficial. It can cut down on the time and labor required to break down whole carcasses in order to fit them into the traps. Moreover, large carcasses and bait are usually brought on the boat and stored in trash bins that take up deck space. For the majority of lobster fishers in San Diego who run operations out of small vessels, the limited deck space can be a challenge. The ground bait could increase deck space and improve safety when setting and pulling traps.

The waste-to-bait products were tested with four fishers in three fisheries in California. The results varied for each fishery as well as the methods for collecting data. For lobster, we relied on collecting data through CDWF commercial logbooks where fisher's record legal and short lobsters. For Dungeness crab, I collected catch data through photos of traps as they were hauled as well as data recorded by the fisher on legal crabs per string. For Rock crab, catch data was recorded on the boat by the researcher which made this testing the most accurate and easiest to complete. For spiny lobster, 2 days of field testing experimental and traditional baits produced positive results. Traps with traditional bait (50 traps) caught 44 total lobsters while the mix of traps (55 traps) with experimental bait, and experimental bait and traditional bait, caught 75 total lobsters. For Dungeness crab, experimental baits were tested in 2 strings and the catch results were compared to traditional baits. The Jackass string showed that the traps with traditional bait clearly fished better (average of 21 crabs per trap) than the traps with experimental bait (average of 5 crabs per trap). The Upper usal 2 string had more positive findings though, and this

may have been due to the increased use of experimental bait (2 bait cups) and a longer soak time of 7 days. For this string, traps with experimental bait caught an average of 10 crabs per trap while traps with traditional bait caught an average of 16 crabs per trap. This was the first time the fisher used bait cups for fish, as the cups are usually only used for squid. The fisher was pleased by the results of the second test with the Upper usal 2 string and thought the experimental bait held up well in the bait cups. The rock crab field testing results were the most promising. The experimental bait was tested in 3 strings and the results proved that it fished similarly to the traditional bait of whole fish carcasses and heads. In total, the experimental bait caught an average of 7 crabs per trap (7 traps) while the traditional bait caught an average of 10 crabs per trap (6 traps). While the experimental bait did not produce the same average number of crabs as the traditional bait, it came the closest to matching the catch results out of all field testing in the 3 trap fisheries.

Limitations

Finding fishers:
Commercial fishers are tough, extremely hard working, and have a deep appreciation and love for the ocean. The majority of fishers who collaborated on this project have spent a lifetime on the water, some even have been fishing for over 40 years. They make a living off what they catch, so each day on the water is important. Choosing to work with commercial fisheries made this project challenging. Finding fishers willing to take the researcher out for fisheries observations was hard and finding fishers to test out experimental baits in their traps was even harder. It would be easier to ask a recreational fisher to test out baits when the stakes are low, but with commercial fishers, you might be hindering their ability to make more money. Through trusted introductions from close friends and stakeholders in the industry, successful connections with commercial fishers were established. The majority of commercial fishers in this project were older, and face to face interaction was valued highly. In each of the fisheries, the researcher went out fishing several times to learn and observe current practices and form trusting relationships. For example, the researcher went lobster fishing three times before being able to test the experimental baits.

Willingness to change for fishers:
A lifetime spent commercial fishing often translates to deeply ingrained habits and preferences During this project many fishers were not willing to change their bait practices in the face of financial risk. Being protective over one's livelihood is a respected quality, but it did make it more challenging to ask fishers to test out something new. Commercial trap fishers have favorite baits, baiting methods, and practices that are passed down from generation to generation. Bait is one of the most important parts of daily fishing operations and without it fishers could not make a living. The high price of bait also makes it a limiting factor, and this may have made the fishers in this project more open to testing out experimental baits, with the hope of collaborating to test and produce a bait product that will provide a cheaper and more sustainable option for future fishing.

Multiple factors affecting field testing :

Commercial trap fishers are faced with many variables that are out of their control that can affect catch rates. There are both biological and physical oceanographic factors at play. Fishers deal with tides, currents, wave action, oxygen levels, and weather conditions that can limit how much they are catching and how much they can fish. Fishers, especially in Northern California, are dependent on the weather and ocean conditions to determine when they can fish. Once the baited traps hit the bottom, the fishers have no control over biological factors such as scavenging from non-target species like sand fleas or predation from larger animals on lobster or crabs in the traps. There is also high variation in catch rates for trap fishing. There can be variation amongst traps, strings, with soak times and for different locations. Fishers could set a string of traps in one location and produce high catch rates of the target species. The following day, or week, the fisher might set the same string in the same location and produce lower catch results. The best way to test out baits is to make the experimental design as consistent as possible and perform a high number of tests so you can look at how the baits performed on average over the duration of the season.

Lobster fishing limitations:
This project began in December, but did not start working with lobster fishers until January. In San Diego, the majority of lobsters are caught in the first several weeks of the season and fishers make the majority of their catch earnings during this time. After January, there are usually only a handful of fishers that keep fishing, and an even smaller amount who fish the entire duration of the season. This translated to a smaller pool of fishers that we could work with as well as less lobsters to catch in the traps to test out bait. In February, fishing is slow, and fishers typically shoot for 10 legal lobsters per day to make fishing efforts economical. February is also when the field testing started, making it challenging to assess the waste-to-bait products' ability to fish. However, during the second half of the lobster season, fishers are targeting the cheapest possible baits that still produce lobsters because the daily catch is low, so it was appealing for fishers to be offered free bait to test in their traps. The fishers did not want to bait a lot of traps with solely experimental bait, so this is why the field tests had a mix of experimental bait and experimental bait combined with traditional bait. Because the project commenced late in the lobster season, there were limited days to conduct field experiments. The researcher was also not able to go out one of the days we were supposed to pull traps with the experimental bait, so fishers were asked to collect data, which was not ideal for both parties. Despite all of this, it was a success to complete field testing for the lobster fishery despite all limitations and obstacles, thanks to the fishers who were willing to help out with this project.

Dungeness crab limitations:
Dungeness crab fishing occurs north of Point Conception. This geographic constraint made it challenging to meet fishers, and conduct field experiments. This also made it challenging to transport a sufficient amount of bait up to testing locations. On top of this geographic constraint, the Dungeness crab season, which normally runs until June or July, closed early this season due to whale entanglements. The entire state fishery closed on April 20th, shortening the amount of time to run any tests. Producing the volume of ground bait and shipping logistics proved challenging. The researcher was not able to get up to Fort Bragg in time for the first set, which made it challenging to set up the experiment. On the set, the fisher had boat mechanical failures, one of the bait blocks was not thawed out enough to use, and a crewmember tested positive for covid. The researcher was unable to go out on the haul due to the covid situation, putting more

responsibility and strain on the fisher to record catch data. The researcher relied on the fisher to take photos of each pot on two strings.

Rock crab limitations:
The rock crab fishery in San Diego is small compared to lobster and Dungeness crab fisheries, making it challenging to find fishers willing to participate. Although this fishery is year round, it is also the least demanding fishery in terms of the amount of fishing days required to set and pull pots. It is not uncommon for fishers to leave their strings soaking for over two weeks and the majority of fishers only go out to check traps once per week. Due to the timeline for this project, it was difficult to find days that aligned for both the fishers' and the researcher's schedules. Rock crab fishers also bait heavy, placing 2-5 large carcasses or heads in the traps. This made it challenging to match the amount of traditional bait with the experimental ground bait as the wood chipper was unable to produce sufficient volume.

Future testing

Why future testing is necessary
Throughout the duration of this project, the scope and purpose of the research shifted. It started as a focus on the business and product development side of creating the bait product, focusing more on the economic feasibility for processors. However, a full economic study was not feasible due to the time parameters for completing the project. The focus then shifted towards field testing the waste-to-bait products to analyze the results. But as we dove deeper into bait research in California for guidance and inspiration, there was limited information. This is where the true potential and impact for this pilot project was realized. Through trial and error, the best methods for conducting this type of research were identified and developed.

This pilot project opens the door for future bait testing and analysis in commercial trap fisheries in California. This project was successful in identifying trap fisheries to work with as well as fishers who are willing to think outside the box to explore new ideas that challenge the status quo for bait and baiting practices. With such a large volume of bait required across these three trap fisheries, there is a need to further explore the topic. While this project focuses on testing out an experimental ground fish bait product, there needs to be more testing of normal baits that fishers are regularly using and relying on to make a living.

Testing out the efficacy of baits is difficult, but it is necessary to determine what baits are producing the highest catch of target species for commercial trap fishers. Uncovering this information could provide fishers with a scientific basis for purchasing baits in order to avoid buying baits that put more economic strain on these fishers that might not actually produce higher catch. If one can determine that fish waste can produce the same catch results as traditional baits like squid, mackerel and sardines that can be used for direct human consumption, fishers may increase the demand for seafood by-products from processors. This would put less strain on processors to dispose of their waste and increase the amount of traditional baits available for human consumption. Further utilization of waste-to-bait products could provide the necessary demand to make it viable for processors to integrate this product production system into daily operations. Fishers receive economic and environmental benefits in

the form of potentially cheaper bait options than traditional baits, as well as the satisfaction of increasing sustainability in their fisheries and collaborating to close the seafood food system in California.

Recommendations for future commercial bait testing:
In order to continue evaluating both experimental and traditional baits, testing needs to begin at the start of the season and continue throughout the entirety of the season. Researchers should provide some form of compensation for fishers at the end of the season to supplement the potential catch that was lost as a result of trying new baits. For experimental design, researchers should place experimental bait and traditional bait in every other trap for strings, and set the strings in the typical locations used by the fishers. When trying to set up the experiment by setting strings with all one type of bait in separate locations, external variables may influence the catch results for strings in some locations more so than others. This makes it challenging to distinguish the bait's ability to fish over the influence from external factors. By testing over the entire season, researchers will be better able to account for changes in catch rates over the duration of the season and uncover trends in the data by having a large enough sample size to dismiss outliers.

The most feasible trap fishery identified for further testing is the rock crab fishery. As this fishery is local to San Diego and its fishers are looking for free bait, this is a good opportunity to test out experimental baits and analyze how well the traditional bait is fishing. Lobster is the second most feasible as there is a local fishery in San Diego. Dungeness crab is the least feasible due to its Northern California location but could have the most impact as it is the most valuable fishery in California and the fishery is heavily reliant on high volumes of whole baits like squid, mackerel, and sardines. If these whole baits are replaced, this could reduce the strain on these important and limited resource bait fisheries.

Conclusions

We successfully created waste-to-bait products that were tested in three commercial trap fisheries in California. This diverted fish waste from landfills and transformed them into a valuable product for California trap fisheries, decreasing waste and improving sustainability both ecologically and economically. The project also revealed an opportunity to study the efficacy of traditional baits, since there has been little research on this topic. This project can be used as a case study or model for future collaborative fisheries research, where processors, fishers, and scientists work together to cultivate benefits for all stakeholders involved. Ultimately, this is a huge area of importance for fisheries that gets almost no attention. Without bait, there is no fishing. It is my hope that this project is the impetus for increased bait research in California and beyond.

Project next steps

I was awarded the Sussman Foundation grant to continue working on this project over the summer and fall of 2022. I will continue to test out baits with rock crab fishers here in San Diego, which will allow me to collect more data and refine my field testing skills for working with commercial trap fisheries. I will also explore further utilization of fish waste for local farming applications by trying to connect processors with farm outlets in San Diego. Currently,

Catalina Offshore Products works with one farm in Escondido to provide seafood byproducts. By connecting COP with more potential farms interested in receiving seafood waste for fertilizer or compost, this will further utilization of this waste and reduce economic burdens on COP to use trash collection services.

ACKNOWLEDGEMENTS
This project would not have been possible without the support and guidance of my capstone committee, Dave Rudie, Sarah Mesnick, Mark Helvey, and Ross Talner. Thank you to all of the staff at Catalina Offshore Products and Scripps Institution of Oceanography. Thank you to all of the fishers who helped out with this project, without their participation, this research would not have been possible.

Appendix:

Data collections sheets

Setting Traps:

String #	Type of Bait	# of Pots	Location	Depth	Time	Other comments
	T E M					
	T E M					
	T E M					
	T E M					
	T E M					
	T E M					
	T E M					
	T E M					
	T E M					

T: traditional bait
E: experimental bait
M: mixed bait

Pulling Traps:

Pulling String #:

Trap #	# short	# legal	Bait remaining	If remaining	Soak Time	Bycatch species	Other comments
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							