Efficacy and Feasibility of Alginate Bait for the Louisiana Commercial Blue Crab (Callinectes sapidus) Fishery

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EFFICACY AND FEASIBILITY OF ALGINATE BAIT FOR THE LOUISIANA COMMERCIAL BLUE CRAB (*CALLINECTES SAPIDUS*) FISHERY

A Thesis

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Master of Science

in

The School of Renewable Natural Resources

by
ElizaBeth L. Clowes
B.S., Ohio University, 2013
February 2015
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ABSTRACT

Louisiana leads all U.S. states in blue crab (*Callinectes sapidus*) landings, but high fuel and bait costs have hindered commercial fishing productivity of Louisiana in recent years. The primary baitfish, Atlantic menhaden (*Brevoortia tyrannus*), has steadily increased in price and decreased in availability, while crab prices remain low. To reduce costs for fishermen, an alternative bait was developed that incorporates shrimp waste into a semi-rigid alginate matrix. Lab testing and preliminary field tests show that shrimp-alginate bait may be a suitable alternative to menhaden for Louisiana crab fishermen. I evaluated bait performance by conducting field sampling to compare catch rates and longevity of standard baitfish and shrimp-alginate bait. I performed seasonal fishery-independent testing at three sites across Southern Louisiana from summer 2014 to spring 2015, and tested the bait on commercial crabbing boats throughout coastal Louisiana during peak crab season in 2015. Catch rates of shrimp-alginate were less than menhaden overall, however, bait performance changed with site and season, and did not significantly differ when I evaluated commercially relevant crab classes. Analysis of remaining bait quantity after fishing showed that shrimp-alginate remains intact as long, or longer, than standard baitfish during peak crab fishing from June through August.

After testing shrimp-alginate bait in the field, I evaluated the economic feasibility of producing the bait with a partial budget supply line. With its current formulation, shrimp-alginate can only be produced at a cost lower than menhaden (currently $0.50/lb.) under optimal production scenarios, however, slight modifications that improve shelf life could dramatically decrease the cost of bait production. Findings from
both field work and feasibility analysis show promise in the alternative shrimp-alginate bait with given improvements to catch rate efficacy and product storage.
CHAPTER 1: INTRODUCTION

1.1 The Blue Crab (*Callinectes sapidus*)

1.1.1 Biology

The blue crab (*Callinectes sapidus*) is a swimming crab of the family Portunidae that originally ranged from Nova Scotia and Maine to northern Argentina, but it also has been introduced in coastal waters of Europe, California, Hawaii, Japan, and the Mediterranean Sea (Ng et al. 2008). Of the eight *Callinectes* species along the U.S. Atlantic and Gulf of Mexico (hereafter Gulf) coasts, *C. sapidus* has been studied most extensively and is the only species with high commercial value (Guillory et al. 2001).

Mature blue crabs exhibit slight color variation but are typically olive green, brown, or grayish on the dorsal surface and off-white on the ventral surfaces (Baldwin and Johnsen 2012). Males have blue pigmentation on the surfaces of the claws, or chelae, and purple tips, whereas females have orange chelae with red tips. In addition to color differences blue crabs show obvious sexual dimorphism in abdomen shape. Juvenile and adult males have a proximally broad and distally narrow T-shaped abdomen, whereas juvenile and adult females have triangular and rounded abdomen shapes, respectively (Baldwin and Johnsen 2012). Blue crabs are easily recognized by their wide, dorsoventrally flattened carapace, which minimizes drag and enables them to move quickly sideways to forage or escape predators (Blake 1985). Lateral spines extend from the carapace and are used by fishery managers to enforce the minimum legal size limit, 5 inches (127 mm), for commercial hard blue crabs (Louisiana Department of Wildlife and Fisheries 2015).
1.1.2 Growth and Reproduction

The blue crab has a complex life history with spatial transitions that accompany phenological changes (Bourgeois et al. 2014). Eggs of *C. sapidus* hatch into planktonic zoea in high salinity waters of inlets and coastal waters and migrate tidally into estuaries and coastal marshes as they grow. After settlement, blue crabs live the remainder of their lives in brackish estuarine habitats, where commercial harvest takes place. During spring and fall spawning migrations females return to high salinity waters to release their eggs, at which point the females are referred to as “sponge crabs” or “berried” females and cannot be legally harvested (Bourgeois et al. 2014).

Blue crabs exhibit stepwise growth by shedding their rigid exoskeleton. The number of postlarval instars is estimated to be 20 for males crabs and 18 for females (Perry and VanderKooy 2015). During the molting process, crabs shed their existing skeleton to expose a new, larger exoskeleton that hardens and fills with body tissue (Smith and Chang 2007). Temperature and food availability strongly influence growth and molting, although variations in salinity and disease prevalence can also influence size at age. Molting reflects only incremental growth, making age estimation difficult, however managers consider the blue crab stock in the Gulf of Mexico to be an annual crop (Bourgeois et al. 2014).

1.1.3 Diet and Foraging

Adult blue crabs consume a diverse selection of epibenthic prey items and may strongly influence estuarine trophic structure. Stomach content and diet analyses have revealed over 99 prey species from various phyla, including molluscs, arthropods (including other blue crabs), chordates, and annelids in addition to occasional plant
matter, carrion, and detritus (Hines 2007). Because of their euryphagous feeding habits, blue crabs have been trophically characterized as generalist predators, scavengers, omnivores, and cannibals (Laughlin 1982). Clearly an opportunistic forager, diet composition is also influenced by spatial (resource patchiness) and temporal (ontogenetic, diel, tidal and seasonal) changes in food availability and use (Hines 2007).

Prior to molting and immediately following, crabs do not feed. During late postmolt and early premolt, blue crabs exhibit crepuscular feeding with peaks in the morning and evening (Clark et al. 1999, Hines 2007). Tidal and seasonal changes in water direction and flow velocity also influence foraging behavior by altering the direction of odor plumes (Weissburg and Zimmer-Faust 1993).

1.1.4 Chemical Cue Detection

Blue crabs rely on olfaction while foraging, especially under turbid water conditions (Koehl 2011). The primary olfactory organs are chemosensory hairs called ‘aesthetascs’ found on the lateral branches of the crab’s antennules. When odor plume are present, crabs capture odorant molecules by rapidly flicking the antennules. With each movement of the antennule the chemosensory hairs widen and contract, efficiently trapping and releasing fluid that the crab uses to determine the presence and concentration of odorants. Each antennule flick captures a fresh sample of water, allowing the crab to continuously ‘sniff’ the environment while navigating toward prey items (Koehl 2011).

Body orientation affects blue crab detection of odorants in chemical plumes (Weissburg et al. 2003). Perpendicular orientation to the flow of a plume enhances chemosensation but increases drag and inhibits movement, so crabs change their
orientation depending on prevailing hydrodynamic conditions. When odor plumes are present at low current velocity, crabs increase the angle of their carapace relative to the odor plume, which increases drag but improves chemical cue detection. Conversely, in high flow conditions, crabs sacrifice olfaction by assuming a body position to decrease drag, reducing locomotory costs (Weissburg et al. 2003). Benthic estuarine environments fluctuate between slow, fairly laminar flows and rough, turbulent flows. Blue crabs are best equipped for chemosensation in hydraulically smooth flowing water, so turbulent flows may hinder successful detection and location of prey (Weissburg and Zimmer-Faust 1993).

1.2 Blue Crab Fishery

1.2.1 History of the Gulf of Mexico Fishery

The early history of recreational blue crab fishing in the Gulf of Mexico is not well known, however commercial crabbing was first reported in the 1880s (Perry and VanderKooy 2015). Early crab fishermen used simple gear types such as long-handled dip nets and drop nets to trap crabs at night. Rapid spoilage limited distribution and hindered growth of the blue crab fishery (Perry et al. 1984) until advances in refrigeration techniques in the late 1800s and early 1900s, which greatly spurred demand (Kennedy et al. 2007). The first commercial processing plant opened in Morgan City, Louisiana, in 1924 and was followed soon after by other plants, although widespread commercial processing did not occur until World War II (VanderKooy 2013).

Many gear types have been used to catch blue crabs along the Atlantic and Gulf coasts (Kennedy et al. 2007). Baited trotlines set in waters 5-15 feet deep were the first major gear used commercially to target hard crabs (Millikin and Williams 1984). Use of
trotlines in the Gulf declined after invention of the crab pot, or crab trap, in 1938. Today, fishermen use crab traps almost exclusively to fish for hard crabs, which make up over 99% of all crab catch by weight in the Gulf of Mexico (VanderKooy 2013). Crab traps are rigid boxlike cages made of hexagonal or square wire mesh, often vinyl-coated, that possess two to four inward-facing funnels. A central compartment, or bait well, is made of smaller wire mesh, holds bait, and limits removal of the bait by crabs and other animals. Oily fish are most often used as bait because they effectively release odorant plumes that attract crabs into the trap (Kennedy et al. 2007).

Sociocultural surveys and trip ticket reports suggest blue crab fishing is a vital source of income for Gulf of Mexico fishermen (Ogunyinka et al. 2012). Survey data show that 55% of Gulf crab fishermen rely solely on fishing as a source of income, 22% of which fish for only crab, and the remainder fish for crab and other fish species. Since 1988, the number of traps per commercial fishermen drastically increased, indicating that fishing effort is rising. A 2013 survey showed that 70% of Gulf fishermen consider operational costs (bait, fuel, oil, and labor) to be a problem, and concurrently 75% of fishermen see imported crabmeat as a threat to their livelihood. High dependence on hard crab catches suggests significant economic gains to Gulf fishermen could be realized with significant declines in operational costs (Perry and VanderKooy 2015).

1.2.2 Louisiana Blue Crab Fishery

Louisiana is the leading Gulf state in commercial crab licenses and total crab landings, both in value and weight. The number of commercial licenses in the Gulf peaked at 4,761 licenses in 2011, with 3,631 of those issued in Louisiana (VanderKooy 2013). Since 2000, approximately 50% of Louisiana license holders actively trap blue
crab according to trip ticket reporting (West et al. 2011). In 2014 alone, Louisiana commercial crabbers landed over 17,957 metric tons of hard, peeler, and soft blue crab, valued at $61.1 million. Combined landings from Texas, Mississippi, Alabama, and Florida’s west coast were only 3,707 metric tons of blue crab, with a value of $12.3 million (National Marine Fisheries Service 2015). Landings, licenses, and annual dockside value illustrate the high economic importance of the blue crab fishery in Louisiana.

Commercial fishermen have no limit on number of traps fished, nor possession or bag limits (Louisiana Department of Wildlife and Fisheries 2015). A 2007 survey showed that Louisiana crab fishermen fish between 200 and 500 traps, with an average of 319 (Bourgeois et al. 2014). A more recent survey (Anderson 2014) found that fishermen ran between 50 and 800 traps, suggesting increasing fishing effort. This trend may have contributed to overfishing in recent years, which was addressed in November 2015 by a suspension of new gear licenses by the Louisiana Department of Wildlife and Fisheries (Lagniappe Fisheries Newsletter, December 2015). Careful monitoring of commercial fishing activity is vital to making appropriate future management actions, and various regulatory measures may be necessary to maintain the desired stock status. Some regulation changes are already under way, including a new Louisiana regulation on trap escape rings. Current regulations require that crab traps have at least two escape rings on the vertical walls of the traps to allow undersized crabs to exit the trap, and new regulations requiring three escape rings will be effective November 2017 (Louisiana House of Representatives 2014). Hard crabs of legal size must be 5 inches (127 mm). 'Berried' females, those carrying an egg-filled sponge on the abdomen during
spawning, must be returned to water (Louisiana Department of Wildlife and Fisheries 2015).

1.2.3 Current Blue Crab Bait

Oily fish like herring and menhaden perform effectively as blue crab bait because high levels of protein and fatty acids produces strong odor plumes that foraging crabs easily detect (Dubrow et al. 1976, Joseph 1985). In Louisiana, the most frequently used baitfish is Atlantic Menhaden (*Brevoortia tyrannus*) (>50%), followed by catfish waste from aquaculture (35%), shad (10%), and mullet (5%) (DeAlteris et al. 2012).

Menhaden (family Clupeidae) are an economically and ecologically important group of marine and estuarine schooling planktivores (Ahrenholz 1991). Menhaden filter feed massive quantities of phytoplankton and zooplankton and are in turn a major prey item for larger piscivorous fishes. Menhaden are primary and secondary consumers as well as prey for keystone predators; therefore they play an essential role in energy transfer of marine trophic webs (Smith and O’Bier 2011).

In addition to bait use, menhaden reduced into fishmeal, fish oil, or fish solubles are valuable resources for the pharmaceutical industry, food processors, and aquaculture because they are rich in omega-3 fatty acids. Gulf menhaden (*Brevoortia patronus*) are plentiful in coastal Louisiana waters, and they support the largest fishery by weight in the state. In 2014, fishermen landed 265,375 metric tons of *B. patronus* in Louisiana waters, valued at $63.4 million (National Marine Fisheries Service 2015). Although Gulf menhaden was formerly the preferred bait choice for LA blue crab fishermen (Perry and VanderKooy 2015), Hurricanes Katrina and Rita caused devastating damage to vessels in the bait fishery (Buck 2005). Because of infrastructure
changes and higher profitability, Gulf menhaden is now harvested almost entirely for reduction uses, and access to Gulf menhaden as bait is limited (Perry and VanderKooy 2015, Vaughan et al. 2010).

Atlantic menhaden has a much larger bait fishery than Gulf menhaden, so Louisiana blue crab fishermen primarily bait their traps with frozen Atlantic menhaden. From 2007-2011, bait fishery landings made up 28% of total Atlantic menhaden landings (Williams 2012), with most fish caught by purse seine in coastal New Jersey and the Virginia portion of the Chesapeake Bay (Smith and O'Bier 2011).

Bait and fuel are the two highest operating costs for commercial crab fishermen, averaging 20% and 17% of trip expenditures, respectively (Perry and VanderKooy 2015). Although blue crab prices have remained stable in recent years, bait and fuel prices are increasingly unpredictable (Buckner 2011). Years of overfishing of menhaden and dramatic fluctuations in fuel prices have exacerbated operating costs, while at the same time technological advances and increased fishing effort have resulted in declines in Atlantic menhaden stocks. A recent stock assessment noted that overfishing occurred in 32 of the previous 54 years (Vaughan et al. 2010). Over the last two decades, the ex-vessel price of menhaden per pound has increased from $0.046 in 1984 to $0.081 in 2012 (National Marine Fisheries Service 2015). In 2012, an update to the Atlantic menhaden fishery management plan established a reduced Total Allowable Catch (TAC) until the 2014 stock assessment. The TAC was equivalent to a 20% reduction in the total Atlantic menhaden landings from 2009-2011 (Williams 2012). During implementation, the price of menhaden continued to rise to $0.088 per pound, a nearly 8% increase from two years prior (National Marine Fisheries Service 2015). Although
the most recent stock assessment has determined that *B. tyrannus* is not overfished and overfishing is not occurring, any future reductions in TAC may decrease availability of baitfish and escalate prices (SEDAR 2015).

The cost of shipping frozen Atlantic menhaden to the Gulf rose steadily for decades until recently, partly as a result of increasing fuel prices. U.S. diesel fuel price increased 256% from $1.107/gal in April 1994 to $3.943/gal in May 2014, and only recently dropped to $2.028/gal in January 2016 (U.S. Energy Information Administration 2016). Given the reduced TAC of Atlantic Menhaden and unpredictable fluctuations in cost of fuel, bait costs are not likely to decrease in the near future.

Catfish waste, the second most common bait, does not present a solution to bait cost and shortage issues are a result of decreased production. The U.S. catfish industry decreased production by 54% from 663 million pounds in 2003 to 301 million pounds in 2014, and in Louisiana alone, areas of catfish production plummeted 95% (-11,475 acres) from 2002 to 2015 (Hanson and Sites 2015). Because of increasingly limited accessibility to the preferred bait products, development of cost-effective alternative bait may therefore be a feasible solution to prevent losses of revenue for the blue crab fishermen.

### 1.3 Alternative Bait Research

Alternative bait research has been conducted for cod (Løkkeborg 1990), lobster (Mackie et al. 1980, Daniel and Bayer 1989), eel and conch (Ferrari and Targett 2003) and sand crabs (Vasquez Archdale and Kawamura 2011), although success has been limited. Bait formulas incorporated derivatives of natural prey items into a semi-rigid carrier matrix or a permeable pouch that slowly released the attractant. In Louisiana, a
cereal grain-based artificial crawfish bait was successfully developed in the 1980s and is now commercially manufactured and regularly used when the temperature of crawfish ponds exceed 21°C (Beecher and Romaine 2010). Although field bait trials for western rock lobster, *Panulirus cygnus* (Ghisalberti et al. 2004), haddock, torsk and ling (Løkkeborg 1991) have proven the effectiveness of artificial baits for certain species, few alternative baits are now manufactured for commercial use, and attempts to develop an alternative blue crab bait have been unsuccessful (Rittschof and Osterberg 2002). The steady rise of baitfish prices, for example the 100% price increase of 100 lb. boxes of menhaden from $12 in 1985 to $24 in 2007 (Perry and VanderKooy 2015), suggests that revisiting formulated alternative bait could be economically favorable for the blue crab fishery.

Commercial marine fisheries are integral to the culture and economy of Louisiana. In addition to blue crab, commercial fisheries exist for crawfish, shrimp, oyster, and numerous finfish species (Louisiana Department of Wildlife and Fisheries 2015). Most commercial seafood requires processing, so seafood waste products are readily available that could be incorporated into bait products. Positive impacts of such bait development include reduced environmental impacts from waste, new manufacturing jobs, and most importantly, decreased operating costs for crab fishermen.

Shrimp waste from commercial processing is a viable attractant that can be incorporated into alternative bait. White shrimp (*Litopenaeus setiferus*) and brown shrimp (*Farfantepenaeus aztecus*) comprise Louisiana’s most valuable fishery and the second largest by weight. In 2014, Louisiana shrimp fishermen landed 18,530 metric
tons of brown shrimp and 30,052 metric tons of white shrimp throughout the year (National Marine Fisheries Service 2015). About one third of all shrimp are discarded during processing, so years with similar shrimp landings may yield 15 to over 20 thousand metric tons of shrimp waste. Shrimp are known to be important prey for blue crab, and the availability of shrimp waste suggests that it could be a viable attractant for an alternative bait.

Laboratory bioassays and preliminary field tests by Anderson (2014) demonstrated potential for shrimp waste as an alternative bait attractant. When incorporated into a semi-rigid seaweed based alginate matrix developed by the University of Delaware, shrimp bait catch rates were similar to Atlantic menhaden catch rates. At a low salinity site (13 ± 2 ppt) menhaden baited traps caught 51% of the total crab catch while shrimp-alginate bait caught 49% of all crabs. At a higher salinity site (20 ± 3ppt) catch rates were 63% and 37%, respectively.

1.4 Significance

Consideration of alternative bait may be necessary to ameliorate rising operating costs in the blue crab fishery, Louisiana’s third largest fishery by weight and value (National Marine Fisheries Service 2015). A substitute bait that is equally or more effective and less expensive than standard bait could reduce the cost of acquiring bait for crab fishermen as well as the cost of waste disposal for shrimp processors. In addition to benefitting two essential Louisiana fisheries, the manufacture of shrimp-alginate bait could create several new jobs and improve the economies of coastal communities.
1.5 Research Objectives

The primary goals of this research were to evaluate the effectiveness of shrimp-alginate bait and determine whether it is a feasible alternative to menhaden. With the same alginate matrix and bait formula used by Anderson (2014), I conducted further investigation of shrimp-alginate bait for catching blue crabs. For my first objective, I tested the alternative shrimp-alginate bait seasonally under fishery independent settings. Second, I evaluated bait performance under commercial crabbing conditions during peak crab season. For both fishery-independent and fishery-dependent testing, I compared catch rates of experimental bait with catch rates of menhaden, the most commonly used baitfish.

For objective three, I determined economic feasibility of shrimp-alginate bait as an alternative to menhaden by creating a budget and calculating bait costs based on the current bait production design in the laboratory. I then scaled up the process to a hypothetical small manufacturing business scenario that may be applicable to the future production of alternative crab bait.

1.6 Works Cited


Hanson, T. and D. Sites. 2015. 2014 U.S. Catfish Database. Fisheries and Allied Aquaculture Department Series No. 1.


CHAPTER 2: FIELD TESTING OF SHRIMP-ALGINATE BAIT

2.1 Introduction

The blue crab (*Callinectes sapidus*) comprises the third largest commercial fishery in Louisiana by weight and value (National Marine Fisheries Service, 2015), and is culturally and economically significant to many coastal communities in the state. As of 2014, LA fishermen held 3,240 commercial crab gear licenses, targeting mostly hard shell crabs with wire mesh crab traps (98% of the volume and 99% of the value of all crabs caught in Louisiana since 2000) (Bourgeois et al. 2014). Although only 1,560 fishermen reported landings in 2013 (Bourgeois et al. 2014), past socioeconomic surveys show that over half of these active crab fishermen rely on fishing as their sole source of income (Guillory et al. 2001).

Operating expenses for Louisiana crabbers are dominated by bait and fuel costs, both of which have increased significantly in recent years (Buckner 2011). Fuel prices rose steadily from the 1990s to 2012 and dropped only recently, with future projections characterized by substantial uncertainty (U.S. Energy Information Administration 2016). Regardless of price fluctuations, there are no alternatives to fuel. However, reducing bait costs, whether by increasing catch rates or improving bait longevity, could yield increased profits to crabbers. Active Louisiana fishermen set between 200 and 500 traps per fishing trip (Bourgeois et al. 2014), for which they use an average of 0.6 lbs of bait per trap (DeAlteris et al. 2012). Atlantic menhaden (*B. tyrannus*) is currently the preferred bait for crab fishing, but menhaden can be difficult and expensive to obtain during warm months. Menhaden longevity decreases with high water temperature in summer months, so fishermen incur higher bait and fuel expenses because they must
re-bait traps every 24-48 hours in most regions (J. Lively, Louisiana Sea Grant, pers. comm. April 17, 2014). Shipping from Virginia and New Jersey also increases bait costs throughout the year (Smith and O’Bier 2011).

Although development of a cheap, effective alternative blue crab bait could improve profits for crab fishermen, little bait research has been conducted for this species. Alternative baits have proven successful for other commercially important crustaceans, including the red swamp crayfish (*Procambarus clarkii*) of Louisiana (McClain and D’Abramo 2006). Previous research has shown that pig blood, chicken byproducts, and beef byproducts have not been effective or practical attractants when incorporated into bait for crab traps (Rittschof and Osterberg 2002). Work at LSU indicates shrimp processing waste incorporated into a semi-rigid alginate based matrix may be an effective and long-lasting alternative to menhaden (Anderson 2014). Shrimp waste (shrimp head and cephalothorax) is widely available from Louisiana shrimp processors and currently has no market. In this project, I compared crab catches in traps baited with either shrimp-alginate or Atlantic menhaden in seasonal fishery-independent and commercial fishery tests to assess the potential of the alginate bait as a viable alternative to LA crabbers.

2.2 Methods

2.2.1 Field Sites

I conducted seasonal fishery-independent sampling from summer 2014 to spring 2015 at four sites in coastal Louisiana of varying habitat types and salinities. Located in distinct hydrologic basins with high crab fishing activity, sampling sites were Rockefeller Wildlife Management Area (Rockefeller) (Mermentau River Basin), Cocodrie
(Terrebonne Basin), Lake Pontchartrain (Pontchartrain Basin), and Grand Isle (Barataria Basin). Commercial crabbers in the Pontchartrain, Terrebonne, and Barataria basins land 31%, 26% and 18%, respectively, of Louisiana hard crabs annually (West et al. 2011). Although the Mermentau Basin contributes a smaller portion of annual landings, it covers a large geographical area. Initial sampling in Lake Pontchartrain revealed an extremely low catch per unit effort (CPUE) during peak crabbing season, so I eliminated Lake Pontchartrain for the remainder of testing (Figure 2.1). Anecdotal information from fishermen since 2010 supported my initial sampling results of few crabs in Lake Pontchartrain due to recent hydrological changes.

Figure 2.1. Fishery-independent sampling locations along Louisiana coastline.

Sites selected for this study covered a typical range of environmental settings found in coastal blue crab harvesting areas and provided bait-testing conditions that were representative of sites used by most Louisiana hard crab fishermen (Table 2.1). Rockefeller Wildlife Refuge differs from the remaining sites because commercial
crabbing is prohibited, although it does experience high recreational fishing pressure most of the year. It is closed to all visitors from December to March.

Table 2.1. Fishery-independent site locations and sampling area descriptions.

<table>
<thead>
<tr>
<th>Site</th>
<th>Geographic Coordinates</th>
<th>Sampling Location Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grand Isle</td>
<td>29° 14' 7.296&quot;, -90° 00' 35.279&quot;</td>
<td>Open channel NW of LA Sea Grant Oyster Hatchery</td>
</tr>
<tr>
<td>Cocodrie</td>
<td>29° 15' 58.284&quot;, -90° 39' 58.608&quot;</td>
<td>Channels ~1 km N of Louisiana Universities Marine Consortium</td>
</tr>
<tr>
<td>Rockefeller</td>
<td>29° 41' 12.840&quot;, -92° 50' 26.772&quot;</td>
<td>20 m wide channel adjacent to Price Lake Road in Rockefeller Wildlife Refuge</td>
</tr>
<tr>
<td>Pontchartrain</td>
<td>30° 22' 41.772&quot;, -90° 10' 33.780&quot;</td>
<td>100-200 m S of Pontchartrain North Shore, 0.5 km W of Tchefuncte River mouth</td>
</tr>
</tbody>
</table>

Fishery-dependent testing also took place in the Mermentau, Terrebonne, Barataria and Pontchartrain basins. Specific sampling locations were determined by fishermen who volunteered to help with the project, although most sites were located within 30 kilometers of each of the four original independent field tests (Figure 2.2).
Where fishermen set large quantities traps over expansive regions, I demarcated areas around subsets of traps to characterize local habitats and water measurements (Appendices A-G). I conducted fishery-dependent sampling in 2015 during June, July, and August, when crab landings and fishing activity annually peak (National Marine Fisheries Service 2015).

2.2.2 Bait Types

Because many commercial fishermen use one whole fish per trap, I designated one whole menhaden or one cylindrical shrimp-alginate bait as a bait unit. I purchased flats of Atlantic menhaden (*B. tyrannus*) from a commercial crab dealer in Slidell, LA (average fish weight approximately 290 g). I made shrimp baits with a mixture of sodium alginate (Scogin HV®), ascorbic (C₆H₈O₆) acid, citric (C₆H₈O₇) acid, sodium bicarbonate (baking soda, NaHCO₃), calcium sulfate solution (CaSO₄), and pulverized untreated white shrimp heads acquired from a shrimp dock in Intracoastal City, LA (Appendices H and I). Shrimp-alginate baits were cylindrical, and approximately 440 mL in volume (average weight of 423 g). During three commercial sampling events, I also added an additional bait treatment of shrimp-alginate bait with 3 mL of Gulf menhaden oil incorporated into the bait (shrimp-oil-alginate) to determine how multiple attractants impacted crab catch rate, and whether fish oil could enhance the experimental bait efficacy. I purchased the processed menhaden oil from a Western Florida recreational fishery supplier.
2.2.3 Fishery-Independent Testing

For each sampling event, I set 30 crab traps, 15 with control bait (Atlantic menhaden) and 15 with the shrimp-alginate bait. Previous studies involving alternative baits and pot fisheries have used between 120 and 160 trap hauls to determine catch rates, so I conducted four sampling periods at each site throughout the year for a total of 120 trap samples per site (Furevik and Løkkeborg 1994, Vazquez Archdale et al. 2008, Furevik et al. 2008, Vazquez Archdale and Kawamura 2011). I also used seasonal sampling to capture intra-annual variation in bait performance relative to changing crab behavior and environmental conditions.

Within 48 hours of trap deployment, I prepared shrimp-alginate baits and randomly selected the order of bait type that would be used for each trap in the sample period. I deployed traps in a line where possible, consistent with the manner used by commercial fishermen in Louisiana. During winter and spring 2015 sampling in Cocodrie, space limitations resulting from commercial trap crowding necessitated that I set several lines of traps adjacent to each other in a grid like arrangement. I set traps at least 20 m apart for all sampling events regardless of trap arrangement to reduce mixing of bait odorants underwater. Soak times were set at 48 hours across seasons based on the consistent soak times used by commercial fishermen between summer 2014 and spring 2015.

During each field trial, I recorded hourly measurements of benthic water temperature with waterproof Onset TidbiT®v2 Temp Loggers attached to the bait wells of two randomly selected traps in each line of traps. Following setting and hauling traps, I measured salinity (ppt) and surface water temperature (°C) with a YSI 63-10FT Sonde.
and determined dissolved oxygen with a Pinpoint® II Dissolved Oxygen monitor (mg/L).
At the conclusion of each 48-hour sampling period I hauled traps and counted, sexed, and measured each crab, noted any anomalies (e.g. injuries, shell rot, missing appendages), and recorded the number, species, and approximate size of bycatch.

2.2.4 Fishery-Dependent Testing

Trap quantity and arrangement varied between regions in the commercial fishery-dependent portion of testing, as sample size was contingent on fishermen preferences and scale of operation. To prevent potential losses and minimize interruption of each fisherman’s routine operation, I tested only a subset of each fisherman’s traps. The number of traps deployed with shrimp-alginate bait ranged from 31 to 82, which I alternated with and compared to an equivalent number of traps baited with the fisherman’s standard choice of bait.

Bait species and quantity of bait per trap varied among fishermen. Two of the four fishermen baited their traps with Atlantic menhaden purchased in frozen flats, while the remaining two baited the majority of their traps with Gulf menhaden, which were much smaller and sold fresh. The fishermen in Terrebonne baited a small number of traps with catfish heads from aquaculture (*Ictalurus punctatus*), and the fisherman in Barataria baited several traps with speckled trout (*Cynoscion nebulosus*) scraps, but these bait types were excluded from analysis. Bait quantity ranged considerably, from a single Atlantic menhaden (defined as one bait unit for independent testing) or 2-3 small Gulf menhaden, to 2-3 larger Atlantic menhaden or 5-6 small Gulf menhaden. Because bait use was inconsistent between sites (fishermen) and within sampling events, I could not attempt to define the ratio of fisherman bait units to my standardized bait unit.
Within 48 hours of sampling, I prepared and refrigerated shrimp-alginate baits. Trap setting took place between 0500 and 1600 in areas selected by the fishermen that were convenient and easily accessible. The fishermen and I alternated between bait types as we moved down lines of traps to maintain simplicity. During baiting, I tagged traps with a colored tag to indicate bait type and recorded GPS locations of each trap on a Garmin GPSMap78 receiver. I measured salinity (ppt) and surface water temperature (°C) with a YSI 63-10FT Sonde for each distinct area of crab traps and noted approximate depth with depth finders installed on the fishing boats. Although one fisherman set all of his traps in the same general vicinity (Lower Mud Lake, Appendices C and F), other fishermen traveled to distinctly different locations within the region (Appendices A-B, D-E, G). Consequently, I refer to each distinct trapping location as an area (1-3 per sampling event) within the larger region.

I returned to each site with the commercial fisherman when they checked traps, between 24 hours and 6 days after baiting. As fishermen pulled up tagged traps, I recorded as much information as possible regarding crab catch and bycatch without inhibiting the fisherman’s normal operating speed. In-boat crab packing and sorting differed among fishermen, especially in areas where female and “factory” (small, or lightweight) crabs were so low in value that the local dealers did not purchase them. Where possible I recorded commercial grade (based on local crab dealer classification) and sex of all crabs, as well as the approximate proportion of remaining bait.

2.2.5 Statistical Analysis

I evaluated bait performance with generalized linear models (GLM – fishery independent) and generalized linear mixed models (GLMM – fishery dependent) of blue
crab catch per unit effort (CPUE) to detect whether crab catch differed significantly between bait types (shrimp-alginate or Atlantic menhaden). I performed all statistical analyses of fishery-independent catch data in R 3.2.2 (R Foundation for Statistical Computing 2015) and used bait type, site, season, and sex as predictor variables of crab catch rate with the canonical log link and Poisson probability distribution. I analyzed fishery-dependent data in SAS 9.4 and used bait type, site, and area as predictor variables, again with the canonical log link and Poisson probability distribution and included a random variable for area, given that fishing practices differed among fishermen and areas. I also investigated differences in size classes caught in fishery-dependent sampling with a rare events model (i.e., generalized linear mixed with a log link and binomial probability distribution). For fishery-dependent data, I also analyzed the quantities of remaining bait post-fishing in SAS 9.4 with GLM or GLMM with canonical log link and Poisson probability distribution and included a random variable for area in the GLMM. To determine significance for all statistical tests, alpha was set at 0.05.

2.3 Results

2.3.1 Fishery-Independent Testing

From July 2014 to April 2015, I sampled on 13 occasions at four field sites. In the summer 2014 sampling season, I caught few crabs (15 individuals) in Lake Pontchartrain and subsequently eliminated the site from further testing. Data from Lake Pontchartrain are excluded from all statistical analyses. In the remaining 12 sampling occasions (three sites, four seasons), I recovered and recorded data from crabs in 356 traps (sample sizes are summarized in Table 2.2). Three traps were not retrieved as a
result of theft or displacement by strong water currents, and one trap was found disturbed with fishing tackle attached and escape rings removed.

Table 2.2. Summary of catch sample sizes from fishery-independent sampling (Pontchartrain was excluded from statistical analysis).

<table>
<thead>
<tr>
<th>Site</th>
<th>Season</th>
<th>Traps Deployed (Retrieved)</th>
<th>Total Legal Size Crabs (Total Sublegal)</th>
<th>Total Legal Size Males (Total Sublegal)</th>
<th>Total Legal Size Females (Total Sublegal)</th>
<th>Total Dead (Sex Unknown)</th>
<th>Bycatch Species Total Bycatch Individuals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grand Isle</td>
<td>Summer 2014</td>
<td>30 (29)</td>
<td>69 (10)</td>
<td>10 (6)</td>
<td>59 (4)</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Fall 2014</td>
<td>30 (30)</td>
<td>23 (7)</td>
<td>9 (2)</td>
<td>14 (4)</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Winter 2015</td>
<td>30 (30)</td>
<td>17 (2)</td>
<td>7 (1)</td>
<td>10 (1)</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Spring 2015</td>
<td>30 (29)</td>
<td>32 (4)</td>
<td>17 (3)</td>
<td>15 (1)</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Cocodrie</td>
<td>Summer 2014</td>
<td>30 (30)</td>
<td>82 (37)</td>
<td>63 (12)</td>
<td>19 (5)</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Fall 2014</td>
<td>30 (28)</td>
<td>88 (3)</td>
<td>78 (2)</td>
<td>10 (1)</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Winter 2015</td>
<td>30 (30)</td>
<td>40 (8)</td>
<td>37 (7)</td>
<td>3 (1)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Spring 2015</td>
<td>30 (30)</td>
<td>16 (17)</td>
<td>10 (11)</td>
<td>6 (6)</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Rockefeller</td>
<td>Summer 2014</td>
<td>30 (30)</td>
<td>84 (52)</td>
<td>67 (49)</td>
<td>17 (3)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Fall 2014</td>
<td>30 (30)</td>
<td>79 (9)</td>
<td>59 (6)</td>
<td>20 (3)</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Winter 2015</td>
<td>30 (30)</td>
<td>193 (13)</td>
<td>63 (12)</td>
<td>130 (1)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Spring 2015</td>
<td>30 (30)</td>
<td>168 (51)</td>
<td>116 (37)</td>
<td>62 (14)</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Pontchartrain</td>
<td>Summer 2014</td>
<td>30 (30)</td>
<td>12 (3)</td>
<td>11 (3)</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Whereas salinity, temperature, and dissolved oxygen were measured, non-independence was expected for these variables throughout each season (Table 2.3). Therefore, model results and subsequent inference used site and season to collectively describe these water quality variables.

I caught a total of 1,086 crabs from Grand Isle, Cocodrie, and Rockefeller after soaking all traps for 48 hours. On average, there were $2.49 \pm 2.75$ SD legal sized ($\geq 127$ mm carapace width (CW)) crabs caught per trap and $0.27 \pm 0.67$ sublegal ($<127$ mm CW) crabs per trap. Among all seasons and sites, menhaden-baited traps ($4.00 \pm 3.69$
Table 2.3. Means ± standard deviation for salinity, temperature, and dissolved oxygen for all sites and seasons (Pontchartrain was excluded from sites after initial sampling).

<table>
<thead>
<tr>
<th>Site</th>
<th>Water Parameter</th>
<th>Summer 2014</th>
<th>Fall 2014</th>
<th>Winter 2015</th>
<th>Spring 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>24.8±2.5</td>
<td>26.0±2.6</td>
<td>22.8±1.6</td>
<td>12.3±0.9</td>
</tr>
<tr>
<td>Grand Isle</td>
<td>Salinity (ppt)</td>
<td>30.0±0.8</td>
<td>25.2±0.9</td>
<td>15.3±1.5</td>
<td>25.6±0.9</td>
</tr>
<tr>
<td></td>
<td>Temperature (˚C)</td>
<td>9.4±1.0</td>
<td>7.7±0.7</td>
<td>9.6±1.1</td>
<td>8.5±2.1</td>
</tr>
<tr>
<td>Cocodrie</td>
<td>Salinity (ppt)</td>
<td>5.1±1.8</td>
<td>11.3±1.3</td>
<td>10.0±1.5</td>
<td>8.2±2.1</td>
</tr>
<tr>
<td></td>
<td>Temperature (˚C)</td>
<td>30.3±0.9</td>
<td>24.0±0.7</td>
<td>15.5±1.5</td>
<td>26.7±0.5</td>
</tr>
<tr>
<td></td>
<td>Dissolved O₂ (mg/L)</td>
<td>8.8±0.8</td>
<td>7.7±0.6</td>
<td>8.8±0.4</td>
<td>6.5±0.6</td>
</tr>
<tr>
<td>Rockefeller</td>
<td>Salinity (ppt)</td>
<td>9.8±1.0</td>
<td>10.1±0.4</td>
<td>10.9±0.2</td>
<td>4.8±0.0</td>
</tr>
<tr>
<td></td>
<td>Temperature (˚C)</td>
<td>31.4±1.6</td>
<td>21.6±1.5</td>
<td>16.2±2.1</td>
<td>24.7±1.8</td>
</tr>
<tr>
<td></td>
<td>Dissolved O₂ (mg/L)</td>
<td>9.8±1.0</td>
<td>8.4±0.0</td>
<td>8.6±0.8</td>
<td>8.3±1.1</td>
</tr>
<tr>
<td>Pontchartrain</td>
<td>Salinity (ppt)</td>
<td>0.4±0.1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Temperature (˚C)</td>
<td>30.3±0.9</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Dissolved O₂ (mg/L)</td>
<td>5.9±1.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Crabs per trap) caught significantly more crabs than shrimp-alginate baited traps (2.14 ± 2.13 crabs per trap, p=0.001). Removal of sublegal sized crabs, making the model more commercially relevant, indicated menhaden (3.19 ± 3.21 legal per trap) caught higher numbers of crabs than shrimp-alginate (1.76 ± 1.96 legal per trap, p=0.002).

Models including and excluding sublegal sized crabs revealed considerable variability in crab catch rate among sites and seasons. Among sites, overall catch (all crab sizes combined) was lowest at Grand Isle (1.41 ± 1.53 crabs per trap, p<0.001, Figure 2.3), with the fewest crabs were caught during spring (3.33 ± 4.18, p<0.001) and winter (3.04 ± 3.66, p=0.005). Traps baited with menhaden caught more crabs (4.00 ± 3.69, p=0.001) among all sites and seasons. Shrimp-alginate bait caught significantly more crabs during summer sampling than other months (2.51 ± 1.47, p=0.030).

Exclusion of sublegal sized crabs from the model showed similar trends, although catch rates with the shrimp-alginate bait were similar to those obtained with menhaden in all
seasons except summer at Rockefeller (shrimp-alginate 1.60 ± 1.05, menhaden 4.00 ± 1.96), which likely influenced trends in raw catch rate data (p=0.045).

Linear models of crab carapace width (CW) showed the largest crabs were males (6.0 cm – 19.5 cm, p<0.001). Crabs caught during spring (average 13.86 cm ± 1.83 SD, p<0.001) and summer (13.96 ± 1.72 cm, p<0.001) sampling were smaller than crabs caught in fall and winter, and crabs at Rockefeller (14.43 ± 1.74 cm, p=0.001) an

Figure 2.3. Legal sized crab catch rater per two day soak ± standard deviation across seasons in (a) Grand Isle, (b) Cocodrie, and (c) Rockefeller, LA. Asterisks (*) indicate significant differences in catch rate per day between bait types.
Grand Isle (15.07 ± 2.20 cm, \( p = 0.002 \)) were significantly larger than those at Cocodrie (14.35 ± 2.10 cm) in spring. At Rockefeller Wildlife Refuge, I caught smaller males (13.84 ± 1.56 cm) than females (15.44 ± 1.56 cm, \( p = 0.0278 \)) across seasons. Exclusion of sublegal sized crabs from the model revealed that bait type influenced the size of crabs caught; crabs caught with shrimp-alginate bait at Grand Isle in summer (15.9 ± 1.54 cm, \( p = 0.006 \)) and Rockefeller in winter (15.68 ± 1.32 cm, \( p = 0.016 \)) were larger than those in menhaden baited traps (15.01 ± 1.18 cm and 15.87 ± 1.26 cm respectively).

Incidental catch of non-target species was very low for most sampling events. Of 97 individuals captured, 47 were hardhead catfish (\( Ariopsis felis \)), caught in fall and spring sampling in Grand Isle. Other bycatch included 6 gafftopsail catfish (\( Bagre marinus \)), 1 Atlantic croaker (\( Micropogonias undulatus \)), 3 black drum (\( Pogonias cromis \)), 18 Atlantic spadefish (\( Chaetodipterus faber \)), 1 sheephead (\( Archosargus probatocephalus \)), 4 pinfish (\( Lagodon rhomboides \)), 5 Southern flounder (\( Paralichthys lethigostoma \)), 1 white trout (\( Cynoscion arenarius \)), 8 stone crab (\( Menippe adina \)), and 2 diamondback terrapins (\( Malaclemys terrapin \)).

2.3.2 Fishery-Dependent Testing

During peak crab fishing months (June-August), I conducted seven sampling events with commercial fishermen. Fishing practices and length of trap soak time differed considerably among fishermen, as did the number of traps and size of region fished. Commercial crabbers in Barataria Basin and Terrebonne Basin fished more extensive areas than did the fishermen in Pontchartrain Basin and the Mermentau River.
Basin. During one sampling event in the Mermentau Basin (Lower Mud Lake), the fisherman ran out of menhaden before shrimp, and in the Terrebonne Basin site, the fishermen spaced out shrimp-alginate baits haphazardly rather than alternately, so analyses of shrimp-alginate baited traps to menhaden-baited traps were not always balanced (Figure 2.4).

<table>
<thead>
<tr>
<th>Region</th>
<th>Site</th>
<th>Area</th>
<th>Soak Days</th>
<th>Date</th>
<th>Water Parameters</th>
<th>Catch Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Salinity (ppt)</td>
<td>Surface Temperature (˚C)</td>
</tr>
<tr>
<td>Eastern Lake Ponchartrain</td>
<td>A</td>
<td>6</td>
<td>11-Jun-15</td>
<td>0.8</td>
<td>29.3</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>6</td>
<td>11-Jun-15</td>
<td>1.8</td>
<td>29.9</td>
<td>1.9</td>
</tr>
<tr>
<td>Mud Lake, Round Lake, Barataria Bay</td>
<td>C</td>
<td>2</td>
<td>10-Jul-15</td>
<td>7.3</td>
<td>30.3</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>2</td>
<td>10-Jul-15</td>
<td>5.1</td>
<td>30.7</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>2</td>
<td>10-Jul-15</td>
<td>5.0</td>
<td>32.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Lower Mud Lake</td>
<td>F</td>
<td>1</td>
<td>17-Jul-15</td>
<td>21.2</td>
<td>28.8</td>
<td>0.5</td>
</tr>
<tr>
<td>Bayous South of Kulac</td>
<td>G</td>
<td>2</td>
<td>22-Jul-15</td>
<td>2.7</td>
<td>30.3</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>2</td>
<td>22-Jul-15</td>
<td>0.7</td>
<td>31.3</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>2</td>
<td>22-Jul-15</td>
<td>0.3</td>
<td>31.4</td>
<td>2.6</td>
</tr>
<tr>
<td>Mud Lake, Round Lake, Barataria Bay</td>
<td>J</td>
<td>2</td>
<td>27-Jul-15</td>
<td>9.8</td>
<td>29.3</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>2</td>
<td>27-Jul-15</td>
<td>9.7</td>
<td>31.6</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>2</td>
<td>27-Jul-15</td>
<td>4.4</td>
<td>32.6</td>
<td>2.4</td>
</tr>
<tr>
<td>Lower Mud Lake</td>
<td>M</td>
<td>1</td>
<td>12-Aug-15</td>
<td>25.2</td>
<td>27.9</td>
<td>0.4</td>
</tr>
<tr>
<td>Bayous South of Kulac</td>
<td>N</td>
<td>2</td>
<td>12-Aug-15</td>
<td>2.0</td>
<td>30.1</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>2</td>
<td>12-Aug-15</td>
<td>5.2</td>
<td>31.4</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>2</td>
<td>12-Aug-15</td>
<td>2.9</td>
<td>32.1</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Figure 2.4. Summary of water parameters and crab catch sample sizes from June to August 2015. (- denotes occasions where crabs were not sorted before packing, or where factory crabs were not retained).

Crabs caught during fishery-dependent sampling were divided into commercially relevant categories where possible: “number one” males (extra large), “number two” males, females, and factory crabs (primarily small males, or larger males in the early inter-molt period with low muscle density). Fishermen in Lower Mud Lake or Lake Pontchartrain did not retain factory crabs, and fisherman in Terrebonne Basin did not
presort crabs, so I was unable to record bait-specific crab counts for the commercial categories.

GLMMs of crab counts and site characteristics revealed non-independence between areas, so I first conducted analyses on crab catch per unit effort (per trap per day) for all sampling events (Table 2.4). Aggregate catch rates and standard deviations of retained crabs showed overall higher bait performance by menhaden ($3.70 \pm 2.09$ crabs per trap per day $\pm$ SD) than shrimp-alginate ($2.28 \pm 1.62$) bait ($p=0.003$). Menhaden also caught more crabs per trap per day than shrimp-oil-alginate ($2.56 \pm 1.58$, $p=0.023$). Shrimp-alginate catch rates did not significantly differ from shrimp-oil-alginate.

**Table 2.4.** Mean combined catch rates per trap per day (± standard deviation) by bait type and crab category, including commercially relevant classes.

<table>
<thead>
<tr>
<th></th>
<th>Total Per Day</th>
<th>Retained Per Day</th>
<th>Ones Per Day</th>
<th>Twos Per Day</th>
<th>Females Per Day</th>
<th>Factory Per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Menhaden</td>
<td>3.70±2.09</td>
<td>3.29±2.00</td>
<td>0.19±0.55</td>
<td>0.36±0.64</td>
<td>1.99±1.88</td>
<td>0.39±0.52</td>
</tr>
<tr>
<td>Shrimp</td>
<td>2.28±1.62</td>
<td>2.03±1.56</td>
<td>0.16±0.47</td>
<td>0.32±0.52</td>
<td>1.40±1.51</td>
<td>0.23±0.29</td>
</tr>
<tr>
<td>Shrimp Oil</td>
<td>2.56±1.58</td>
<td>2.31±1.64</td>
<td>0.20±0.49</td>
<td>0.25±0.48</td>
<td>1.92±1.94</td>
<td>0.19±0.45</td>
</tr>
</tbody>
</table>

Comparisons of individual crab categories did not reveal significant differences between catch rates by menhaden and shrimp-alginate baits across crab size classes. A rare events model showed that number one crab catch rate did not significantly differ between menhaden ($0.19 \pm 0.55$) and shrimp-alginate bait ($0.16 \pm 0.47$) or between menhaden and shrimp-oil-alginate ($0.20 \pm 0.49$; all $p>0.664$). Number two male catch rate also failed to exhibit significant differences between menhaden ($0.36 \pm 0.64$) and shrimp-alginate ($0.32 \pm 0.52$) as well as menhaden and shrimp-oil-alginate ($0.25 \pm 0.48$; all $p>0.252$). Factory crab catch rates were significantly higher with menhaden ($0.39 \pm 0.52$).
0.52) than shrimp-oil-alginate bait (0.19 ± 0.45, p=0.011), and both exhibited a non-significant trend of higher catch rates than shrimp-alginate (0.23 ± 0.29; p=0.120). Although menhaden baited traps (1.99 ± 1.88) appeared to catch more females than shrimp-alginate (1.40 ± 1.51) or shrimp-oil-alginate (1.92 ± 1.94), models assessing female catch were non-significant (p=0.252).

When I examined bait performance for individual sampling events, I found results similar to the analyses of the aggregated data (Figure 2.5). For each sampling event, with the exception of Slidell and the second Lower Mud Lake sampling, menhaden caught significantly more retained crabs than shrimp-alginate. Inclusion of the shrimp-oil-alginate treatment showed that during Barataria sampling 2, menhaden again caught significantly more retained crabs (3.66 ± 1.70) than shrimp-alginate (2.65 ± 1.54, p=0.0056) and shrimp-oil-alginate (2.98 ± 1.83, p=0.0247), whereas shrimp and shrimp-oil-alginate baits did not differ. During Dulac sampling 2, menhaden caught more crabs (3.76 ± 1.39) than shrimp-alginate (2.00 ± 0.68, p<0.001), menhaden caught more than shrimp-oil-alginate (1.68 ± 0.83, p<0.001), and shrimp-alginate caught more than shrimp-oil-alginate (p<0.001). Assuming non-independence of areas in the analyses of the fishery-dependent data, significantly more shrimp-alginate remained in the bait well than menhaden (p=0.002), and significantly more shrimp-oil-alginate bait remained than whole menhaden (p<0.001).
Figure 2.5. Aggregate catch rates of retained crabs per trap per day + standard deviation for all fishery-dependent sampling events. Asterisks (*) indicate significant differences in model fit catch rate per day between bait types.

2.4 Discussion

Overall, fishery-independent and fishery-dependent results suggest that menhaden catches more crabs than shrimp-alginate bait. However, when crabs are separated into commercially relevant categories (i.e. number ones, number twos, females, and factory crabs) there are no apparent differences in catch rates between the two baits. Additionally, visual evaluation of bait remaining after trap deployment (from fishery-dependent sampling) show that in summer months, shrimp-alginate bait remains intact longer than menhaden. These findings indicate that although there may be limitations to the use of shrimp-alginate bait, it may be preferable under specific fishing conditions, and could serve as an adequate alternative if menhaden was unavailable.

Crab catch throughout the year was poor for fishery-independent sampling at two of three sites where fishing pressure is high. I caught large numbers of crabs only at
Rockefeller Wildlife Refuge, where commercial fishing is prohibited and recreational fishing is prohibited from December-March. I consistently observed this trend throughout the year, which supports the notion that year round commercial fishing pressure may strongly impact local blue crab abundance. Because of low sample sizes and limitations in fishery-independent sampling, bait performance may be best represented in this study by the commercial fishery-dependent results.

2.4.1 Bait Performance in Fishery-Independent Testing

Throughout sampling, I found male crabs tended to be larger than females. This finding is consistent with the commercial industry practice of selling the largest male crabs as “number ones” (>6 inch CW) and “number twos” (>5.5 inch CW) separately from smaller males and females, although these specific size classes can change seasonally and with market shifts (Bourgeois et al., 2014).

Menhaden bait performance was higher than shrimp-alginate at the sites selected for this study, with the exception of summer sampling. Previous blue crab bait work similarly found that experimental artificial baits made with meat processing waste attracted significantly fewer crabs during field tests than natural unprocessed baits like menhaden, despite the attractant (poultry) having high concentrations of amino acids, similar to natural fish baits (Rittschof and Osterberg 2002). Similar to the work conducted by these authors, I also sampled seasonally, but my baseline crab catch rates differed substantially from the earlier study and cannot be compared directly. In their study, average crab catches ranged from 3.8 crabs/trap with the least effective bait to 22.8 crabs/trap with the most effective (Rittschof and Osterberg 2002), whereas my maximum crab per trap rate only reached 8.4 crabs/trap over a two day soak period and
was frequently below 1.0 crab per trap per day. The highest catch rates that I observed were in Rockefeller Wildlife Refuge, which is an atypical site because it does not experience any commercial fishing pressure. Although high catch rates in Rockefeller made the models more robust, they probably do not accurately reflect commercial fishing conditions where crabbing pressure is much higher. Seasonal catch differences or low site quality may have affected my crab catch rates and subsequently led to models with lesser fit. Finding very high quality crabbing sites is essential for future work in bait evaluation.

Despite generally lower catch rates, shrimp-alginate was most effective during summer. Improving the overall ability for shrimp-alginate to attract crabs is necessary, and may require an increase in the attractant concentration (shrimp waste), or in refinement of the attractant composition. Although Anderson (2014) looked at protein diffusion in the current shrimp-alginate bait formula, a detailed analysis of the total dissolved amino acids in shrimp heads compared to menhaden may shed more light on ways to improve the bait, similar to Løkkeborg’s (1990) work on an alternative long-line bait.

2.4.2 Bait Performance in Fishery-Dependent Testing

Similar to my findings with fishery-independent sampling, commercial testing showed that overall bait performance by shrimp-alginate bait was lower than menhaden. However, models of commercially relevant categories of crabs including “number ones”, “number twos”, females, and “factory” crabs showed that there were no significant differences in catch rate between menhaden and shrimp-alginate. This finding is especially important for commercial crab fishing because commercial grades strongly
impact profit, in particular because number ones and number twos are often far more valuable than females and factory crabs. Fishermen often target specific size classes or crab sex based on the market value of the respective categories, so using shrimp-alginate bait may be more beneficial for fishermen that desire more valuable crabs (i.e. number ones and number twos) even if they catch fewer crabs overall.

Catch rate models revealed that addition of fish oil made no significant improvements in attraction of crabs to traps, and it had no effect on bait longevity. This finding may be explained by the tendency for crabs to exhibit an aversive behavioral response to multiple chemical cues when mixed in a turbulent water plume (Weissburg et al., 2012). This phenomenon occurs because the homogenization of multiple odor cues in a plume often suppresses ability to track odors. As a result, I suggest exercising caution when incorporating of several different attractants into future iterations of alginate bait, as they may produce an unfavorable response by foraging crabs.

Analysis of bait persistence for fishery-dependent testing indicated higher longevity of alginate bait than menhaden in crab traps. Surveys of commercial fishermen (Anderson 2014) suggest that this characteristic is desirable for crab bait, as increasing the length of soak days (between checking traps) can reduce fuel and labor costs. Rapid consumption of menhaden currently inhibits the practice of soaking traps for long spans of time. To further improve shrimp-alginate longevity in the trap bait well, I suggest that various volumes of alginate bait be tested against various amounts of menhaden. This would help determine if surface area factors into bait breakdown, and would provide information on the differing amounts of menhaden used by commercial fishermen in their traps. Another way to improve bait longevity may involve the use of a
fine protective mesh. In bait experiments with artificial baits for the sand crab (*Ovalipes punctatus*) fishery, researchers created a rigid tablet of bait encased with a mesh fruit bag to maintain shape (Vasquez Archdale and Kawamura 2011). If, in addition to refining the attractant concentration, a protective mesh were added to shrimp-alginate, the bait could significantly outlast, and present a viable alternative, to menhaden, particularly during peak crab fishing months (June-August). Atlantic menhaden is also most difficult to obtain during the warmest months of the year, when refrigerated transportation operates least efficiently (J. Lively, Louisiana Sea Grant, pers. comm. April 17, 2014). Availability of an alternative bait at this time of year might prove to be especially useful.

2.4.3 General crab fishing observations and suggestions for further testing

Initially, I planned to directly compare bait performance results of fishery-independent and fishery-dependent testing. However during commercial sampling, I found that fishermen’s practices for processing crabs and running traps were highly variable across sites. In most cases, fishermen sorted crabs immediately after pulling up traps. Only one fisherman graded at a dockside processor. The tendency for fishermen to retain sublegal crabs also varied across sites, as some carefully checked that crabs exceeded 5" (>127 mm) and others did not. Finally, not all fishermen retained “factory” crabs, small crabs (mostly male) with low muscle density. All fishermen that participated in the project reported that crab catch has decreased in recent years throughout the state, which has been noted by Louisiana Department of Wildlife and Fisheries, which recently put a moratorium on new crab gear licenses (Carl Britt, Louisiana Department of Wildlife and Fisheries, pers. comm. October 1, 2015). This trend in decreasing catch
may require management or enforcement attention, especially in areas where landings of sublegal sized crabs are substantial.

Models for both fishery-independent and fishery-dependent testing often failed to optimize because available crab catch data did not meet the necessary assumptions. More crab catch data would improve these models. Because of gear and time limitations, I was unable to trap more than 30 traps per fishery-independent sampling event and was limited to sampling areas close to each boat launch. Traveling as little as 15 km could considerably improve catch rates, as I detected from sampling near Grand Isle, LA. The location of my fishery-independent traps were just south of the areas where a fisherman set traps for Barataria samplings 1 and 2, yet catch rates were far lower in the southern end of the basin. Testing expansive areas with more crab traps to capture a comprehensive gradient of environmental characteristics and a shifting crab population may optimize data collection for future work.

In summary, the most important finding of this research was that although catch rates were low across bait types, commercially relevant classes of crabs ("number one" males, "number two" males, females, and factory crabs) exhibited no significant differences in catch rate with different bait types. Field sampling under fishery-independent and fishery-dependent conditions showed that the prevailing bait type used by Louisiana crab fishermen catches overall more blue crabs that the current formulation of shrimp-alginate bait. However, catch rate varied significantly among sites and across seasons. Potentially, a shrimp-alginate bait could catch similar numbers of commercial sizes and reduced numbers of sublegal crabs, and could present an unexpected benefit in reduced sorting time. Analysis of remaining bait quantity during
commercial testing revealed that shrimp-alginate bait remained in traps significantly longer than menhaden. Further field testing is necessary to clarify trends in bait efficacy of shrimp-alginate bait, and adjustments to volume or attractant concentration may be necessary.

2.5 Works Cited


CHAPTER 3: FEASIBILITY ANALYSIS OF SHRIMP-ALGINATE BAIT

3.1 Introduction

Field experimentation is imperative for all bait research because it demonstrates bait efficacy and longevity under natural conditions, and because undesirable field results provide the impetus for bait refinement or product rejection. Neutral or even strongly positive field results, on the other hand, do not necessarily justify manufacturing a bait product until economic feasibility is established for a reasonable manufacturing scale (Gonçalves et al. 2015). In the case of shrimp-alginate bait, field test results (Anderson 2014) suggested that for the commercially important Louisiana blue crab (Callinectes sapidus) fishery, experimental shrimp bait is comparable in efficacy and superior in longevity to the increasingly expensive conventional baitfish, menhaden (Brevoortia tyrannus and Brevoortia patronus). Preliminary analysis of the bait also showed that its chemical constituents could be acquired cheaply enough to offer substantial savings to commercial crab fishermen who use shrimp-alginate bait (Anderson 2014). Because of encouraging preliminary findings, future production of shrimp-alginate bait is under consideration. However, before steps are taken to produce the novel bait, it is essential to determine whether a bait production enterprise is lucrative for a manufacturer and also cost-effective for crab fishermen.

To evaluate economic feasibility of production, I created a hypothetical manufacturing scenario with multiple levels of production volumes based on blue crab bait demand and on scaled-up laboratory requirements for equipment, chemical, storage, and labor to produce shrimp-alginate bait. To capture the feasibility for fishermen in the analysis, I set a bait price threshold over which production would be
cost-prohibitive to fishermen, equivalent to the current cost of menhaden. As my primary objective for the analysis I sought to identify areas for future bait improvement, from both the manufacturer and consumer fishermen perspectives.

3.1.1 Framework for Feasibility Analysis

For the design of a hypothetical manufacturing scenario, I followed a basic aquatic seafood product plant design outlined by Wheaton and Lawson (1985). Assessing feasibility of a seafood product requires familiarity with raw inputs, market studies, objectives, and product characteristics. Landings data and market surveys are both available for the Louisiana shrimp fishery (National Marine Fisheries Service 2015, Isaacs and Lavergne 2008), and desired qualities of blue crab bait are known from recent survey data (Anderson 2014). Other key factors that determine whether a product is a worthwhile investment include materials, labor, utility, and equipment costs, as well as preparation losses and waste disposal, all of which are estimated for the purpose of this study. After assessing profitability, the proposed product should be accepted, altered, or dropped from consideration (Wheaton and Lawson 1985).

3.1.2 Shrimp-Alginate Bait Components and Laboratory Processing

Previous bait research shows that alginate (also known as sodium alginate or alginic acid) is an effective carrier for natural bait attractants in water (Ferrari and Targett 2003, Rager 2007). Alginate is a polysaccharide \((\{(C_6H_{10}O_6)_{n}\})\) extracted from brown seaweed \((Laminaria hyperborea)\) and processed into gelling agents of variable quality and viscosity. Upon addition of \(Ca^{2+}\) solution, alginate forms a semi-rigid matrix and slowly releases attractant molecules when the bait is placed in an aquatic
environment (Anderson 2014). The alginate formula used for this study contains sodium alginate (Scogin HV®) made by FMC Biopolymer, ascorbic (C₆H₈O₆) and citric (C₆H₈O₇) acids, and sodium bicarbonate (baking soda, NaHCO₃), to which the attractant (shrimp waste) and hardening calcium sulfate (CaSO₄) solution are added (Appendices A and B).

All components of the current shrimp-alginate formula are widely available in Louisiana. Peak crabbing months (June-August) coincide with months of high shrimp landings, indicating that shrimp waste is readily accessible throughout the year when bait demand is high (Figure 3.1). Most shrimp in Louisiana is sold head-off (26.2% by volume) or as peeled meat (71.4% by volume) (Isaacs and Lavergne 2008), and currently shrimp waste has no market. Removal of the head generates approximately 33% waste by weight; peeling, de-veining, and de-heading generates about 50% waste by weight (Thu Bui, Louisiana Cooperative Extension, pers. comm. August 26, 2015). Conservative calculations of shrimp head waste availability (33% of whole shrimp weight) based on average combined landings of brown and white shrimp from 1990-2014 show that between 341 (March) and 9,072 (June) metric tons of waste are generated monthly, with waste generated year round (Fig. 3.1). If 50% of all shrimp head waste from March or June was manufactured into shrimp-alginate baits, 1.51 million and 40.14 million baits could be produced in those months, respectively. In 2011, Louisiana crab fishermen used 19 million pounds of bait, equivalent to approximately 31.7 million bait units (DeAlteris et al. 2012), so the shrimp waste currently generated far exceeds the amount necessary to manufacture baits for the entire Louisiana crab fishery. Additionally, true quantities of shrimp waste generated by processors is likely
even greater in volume than these estimates for a typical year, as these monthly averages include anomalous years (2005 and 2010) with infrastructure damage or fishery area closures from Hurricane Katrina and the Deepwater Horizon oil spill, respectively (US DOC 2007, Sumalia et al. 2012).

![Figure 3.1. Average Louisiana monthly commercial landings (1990-2014) for blue crab (C. sapidus) and the two key shrimp species: white shrimp (L. setiferus) and brown shrimp (F. aztecus) (National Marine Fisheries Service, 2015).](image)

Sodium alginate, although not produced in Louisiana, is made from a fast-growing macroalgal species off the coast of Norway, which has been managed and harvested successfully for over 50 years (Vea and Ask 2011). Alginates are sold by various chemical and food supply companies, and they range widely in price. Food grade and industrial grade versions of the other bait chemicals (ascorbic acid, citric acid, sodium bicarbonate, and calcium sulfate) can be easily shipped to any location in Louisiana. With the exception of shrimp waste, which must be frozen if held long-term,
all chemicals used for alginate bait may be purchased in bulk at reduced rates and kept in dry storage for several years.

3.1.3 Partial Budget Approach to Manufacturing

Although several US patents mention alginate baits (Ligett 1981, Cox 1982, Morton and Rudi 2000, Ollis et al. 2004), development of a full supply line for our shrimp-alginate bait is hypothetical and untested. Most bait components can be easily obtained, however, dependence on a seasonal constituent (shrimp waste) for a seasonally variable market (crab fishing) makes it a high-risk investment for a potential investor. A partial budget approach, rather than a new enterprise, is recommended if this product were pursued by a business (R. Caffey, Louisiana State University, pers. comm. October 1, 2014). Partial budgeting techniques, used commonly in aquaculture and farming operations (Doupé and Lymbery 2002, Mohanakumaran Nair et al. 2006), assess the feasibility of changes made to a pre-existing operation with a simple formula that takes into consideration increased and decreased revenues and increased and decreased costs for a net change in revenue (Lane et al. 1997). To develop a partial budgeting analysis for shrimp-alginate bait, I developed a list of basic overarching assumptions on which I based my feasibility assessment:

- An existing business (e.g. a seafood processor located in close proximity to crab and shrimp fishing areas, or an urban industrial facility) has available space to which a bait manufacturing operation may be added;
- The facility’s designated bait manufacture area has adequate space and utility hookups as well as appropriate commercial zoning permits;
• The business is easily accessible for trucks with shipments of chemicals, shrimp, or other necessary supplies;
• Waste disposal is included in the pre-existing operational costs for the facility;
• The manufacturer has the capability to make formula changes or production alterations as deemed necessary;
• To reduce initial costs for the business, the owner is assumed to be an operator that will perform all obligations required outside the duties of hired labor, and therefore receives back-end pay annually.

3.2 Methods

I evaluated the economic feasibility of shrimp-alginate bait by designing a hypothetical supply line to be added to a pre-existing facility, and by estimating annual costs of operating the supply line. I created three general production scenarios (small, medium, and large volume) based on approximately 1%, 5%, and 10% of Louisiana bait demand, given that fishermen use an average 0.6 lb of bait per trap (DeAlteris et al. 2012). Each hypothetical scenario would produce 300,000, 1.5 million, and 3.0 million bait units respectively. I assessed economic feasibility of each scenario by estimating key parameters associated with capital and operating expenses of similar enterprises, and by evaluating breakeven cost (BE) and net revenue under a variety of conditions. I set the alginate-bait price threshold at $0.30/bait unit, which is equivalent to the current (2016) cost of one bait unit of menhaden, or 0.6 lbs of menhaden at $0.50/lb (T. Luke, Luke’s Seafood, and G. Bauer, Pontchartrain Blue Crab pers. comm., Jan 5, 2016). Budget parameters are listed in Table 3.1 (Kalleras et al. 2010).
Table 3.1. Budgeting parameters for economic feasibility analysis.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Abbreviation</th>
<th>Calculation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Fixed (Equipment) Costs</td>
<td>TFC</td>
<td>$PI + D$</td>
<td>Principle and Interest plus Depreciation</td>
</tr>
<tr>
<td>Total Variable (Operating) Costs</td>
<td>TVC</td>
<td>$Ta + Xa + Ea + La + C(Ta + Xa + Ea + La)$</td>
<td>Transportation, Chemicals, Annual Electricity Cost ($Ea = Ec$), Labor, and Operating Contingency (10%)</td>
</tr>
<tr>
<td>Total Annual Costs</td>
<td>TAC</td>
<td>$TFC + TVC$</td>
<td>Sum of Fixed and Variable costs</td>
</tr>
<tr>
<td>Total Projected Revenue</td>
<td>TAR</td>
<td>$Sa \cdot P$</td>
<td>Revenue generated from sales: Annual Sales multiplied by Market Price of bait</td>
</tr>
<tr>
<td>Net Return to Owner</td>
<td>NRO</td>
<td>$TAR - TAC$</td>
<td>Projected Annual Revenue after Total Annual Costs</td>
</tr>
<tr>
<td>Breakeven Cost</td>
<td>BE</td>
<td>$TAR \div Q$</td>
<td>Total Annual Costs divided by Annual Sales (in bait units)</td>
</tr>
</tbody>
</table>

To calculate total fixed costs (TFC), I first generated capital (equipment) costs (F) for each of the three hypothetical supply lines by scaling up equipment needs from laboratory bait production (Table 3.2). For each equipment item used in the laboratory, I researched industrial analogs that could perform the same function, and could process volumes of material relevant to each of the three production scenarios. Several industrial substitutions for laboratory equipment were not practical, so I made substitutions with assistance from a manufacturer that makes alginate pet products (David Fluker, Fluker Farms, Baton Rouge, LA, pers. comm., September 17, 2015). For example, I made all shrimp-alginate baits in the laboratory with deionized (DI) water to reduce microbe growth, and a microwave oven to heat water. Industrial capacity DI systems are extremely cost prohibitive and microwave ovens are not practical to heat large amounts of water, so I substituted a steam kettle and UV light disinfection tube for these functions in the manufacturing scenarios. Similarly, addition of calcium hardening
solution in the lab was slow and labor intensive, and cannot be produced efficiently in
mass quantities by hand. To replace manual bait mixing with a drill and paint-mixing bit,
a dropper with a wire cutter could be used to pump alginate (with a peristaltic pump) into
a calcium solution bath for hardening. This pump system could be controlled with
automation to reduce labor requirements.

Table 3.2. Breakdown of capital costs based on scale-up of laboratory production.

<table>
<thead>
<tr>
<th>Manufacture Scale Equipment</th>
<th>Laboratory Scale Equipment</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blender, large capacity</td>
<td>Food processor</td>
<td>Shrimp pulverization</td>
</tr>
<tr>
<td>Peristaltic pump</td>
<td>Manual pouring</td>
<td>Transfer of alginate liquid to dropper</td>
</tr>
<tr>
<td>Water pump</td>
<td>Manual pouring</td>
<td>Recirculaes calcium hardener</td>
</tr>
<tr>
<td>UV tube</td>
<td>Deionized water system</td>
<td>Microbe reduction in recirculating calcium hardener</td>
</tr>
<tr>
<td>Automation</td>
<td>Manual bait preparation</td>
<td>Equipment coordination</td>
</tr>
<tr>
<td>Cutter</td>
<td>Manual bait preparation with</td>
<td>Separation of alginate into individual baits</td>
</tr>
<tr>
<td></td>
<td>drill and paint mixing bit</td>
<td></td>
</tr>
<tr>
<td>Head of dropper</td>
<td>Manual bait preparation with</td>
<td>Funnels shrimp alginate mixture into tubes for cutting</td>
</tr>
<tr>
<td></td>
<td>drill and paint mixing bit</td>
<td></td>
</tr>
<tr>
<td>Hood</td>
<td>Ventilation system</td>
<td>Ventilation</td>
</tr>
<tr>
<td>Steam kettle (80 gal.)</td>
<td>Deionized water system / Micro wave</td>
<td>Microbe reduction; extension of bait storage life</td>
</tr>
<tr>
<td></td>
<td>oven</td>
<td></td>
</tr>
<tr>
<td>Drum roller</td>
<td>Manual bait preparation with</td>
<td>Dry ingredient mixing</td>
</tr>
<tr>
<td></td>
<td>drill and paint mixing bit</td>
<td></td>
</tr>
<tr>
<td>Trough / Tank</td>
<td>Individual small containers used for</td>
<td>Bait gellation</td>
</tr>
<tr>
<td></td>
<td>preparation</td>
<td></td>
</tr>
<tr>
<td>Plastic storage drums</td>
<td>Small canisters</td>
<td>Dry chemical storage</td>
</tr>
<tr>
<td>Refrigeration</td>
<td>Standard refrigerator unit</td>
<td>Storage during hardening</td>
</tr>
<tr>
<td>Walk-in freezer</td>
<td>Chest freezer</td>
<td>Raw shrimp waste storage</td>
</tr>
<tr>
<td>Heavy duty bulk containers</td>
<td>Restaurant grade storage bins</td>
<td>Overnight bait storage during hardening</td>
</tr>
<tr>
<td>Contingency</td>
<td>N/A</td>
<td>10% of all start-up expenses</td>
</tr>
</tbody>
</table>

48
I estimated capital (equipment) costs ($F$) for each specific production scenario. Production capacity of most items could be sufficiently increased from the small production volume to medium and large volumes with longer run time, however additional refrigeration and freezer storage, a larger capacity peristaltic pump, and a forklift were necessary additions to the medium and large production scenarios. Where possible, I found multiple equipment estimates and used the average of all estimates in my capital cost calculations. For equipment that would require construction, I consulted with David Fluker (Fluker Farms, Baton Rouge, LA, pers. comm., September 17, 2015) for assistance in determining quantity and cost of necessary parts, after which I verified the estimates.

To calculate TFC, I assumed that the manufacturer would procure a loan in the amount of combined start-up equipment expenditures ($F$) plus 10% contingency, and would make uniform loan payments over a ten-year (120 month) term ($t$) with an interest rate ($R$) of 10%. I used a standard loan amortization formula that takes these variables into account (Karellas et al. 2010):

$$PI = F \left( \frac{r(1+r)^t}{(1+r)^{1-t}} \right)$$

Because the hypothetical supply line is tailored specifically to a product with no analogs in the bait or food industry, the assembly line would be difficult to sell if bait production discontinued. Absence of a secondary function makes this supply line a high risk investment, therefore a higher interest rate, up to 15%, would also be appropriate for conservative calculations of feasibility (R. Caffey, Louisiana State University, pers. comm. January 27, 2016). Depreciation was set at 7 years (14.3% per year) for supply line equipment, according to the guidelines set by the IRS Assets Class 20.4 for fish.
processing equipment (equivalent to depreciation for food production and manufacturing equipment). Principle and interest were combined with depreciation for total annual fixed costs:

\[ TFC = PI + D \]

I calculated total variable costs (TVC) by estimating annual transportation \((T_a)\), chemical \((X_a)\), electricity \((E_a)\), and labor \((L_a)\) needs for small, medium, and large production scenarios, with 10% operating contingency \((C)\):

\[ TVC = T_a + X_a + E_a + L_a + C \left( T_a + X_a + E_a + L_a \right) \]

I established parameters associated with TVC based on standard business practices, previous research, or laboratory scale estimates (Table 3.3). I estimated transportation cost \((T_a)\) by defining a baseline delivery route (circular route including Slidell, New Orleans, Houma, Morgan City, New Iberia, and Intracoastal City) and shrimp pickup location (Intracoastal City), and multiplied distance by the 2015 average freight shipping cost per mile of $1.703/mile (Torrey and Murray 2015). For most scenarios I assumed that the baseline delivery route would include shrimp pickup, with the exception of a local-distribution only scenario. I calculated chemical costs for each production scale based on the chemical volume necessary for a year’s supply, and I used readily available prices from online chemical suppliers to determine the average price of each chemical (per bait unit). Electricity costs included refrigeration, freezer, and equipment electricity use, and were approximated from annual estimates of electricity use by each type of equipment. Labor parameters were based on part-time facility operation (3 days per week) with common hours and wages (Table 3.3), and contingency was set at 10% as it was for TFC.
Table 3.3. Model assumptions associated with total annual costs.

<table>
<thead>
<tr>
<th>Variable Description</th>
<th>Variable</th>
<th>Assumptions</th>
<th>Source/Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bait produced (units/year)</td>
<td>Q</td>
<td>300,000 units, 1,500,000 units or 3,000,000 units</td>
<td>Based on calculations of 2011 bait use by Louisiana crab fishermen (DeAlteris et al., 2012)</td>
</tr>
<tr>
<td>Sales (% of baits)</td>
<td>S</td>
<td>50% (conservative), 75% (liberal), or 100% (very liberal)</td>
<td>(R. Caffey, pers. comm. November 20, 2015)</td>
</tr>
<tr>
<td>Sales per year (# baits)</td>
<td>$a</td>
<td>Variable</td>
<td>Calculated. $a = S • Q</td>
</tr>
<tr>
<td>Market price ($/baits)</td>
<td>P</td>
<td>Threshold of $0.30/bait</td>
<td>Current menhaden bait price of $0.50/lb. (T. Luke and G. Bauer, pers. comm. January 5, 2016)</td>
</tr>
<tr>
<td>Chemical cost ($/unit)</td>
<td>X</td>
<td>$0.14 for small, $0.13 for medium and large</td>
<td>Based on average of 3+ estimates for one-year supply of each chemical purchased in quantities relevant to S,M, and L production volume scenarios</td>
</tr>
<tr>
<td>Supply Waste (%/bait)</td>
<td>W</td>
<td>3%</td>
<td>Processing inefficiencies (e.g. residual shrimp/alginate on containers) estimated from laboratory production</td>
</tr>
<tr>
<td>Depreciation (%/year)</td>
<td>D</td>
<td>14.3%</td>
<td>Food production and manufacturing depreciation rate (Assets Class 20.4, IRS 2015)</td>
</tr>
<tr>
<td>Interest rate (%)</td>
<td>r</td>
<td>15% conservative, 10% liberal</td>
<td>(R. Caffey, pers. comm. November 20, 2015)</td>
</tr>
<tr>
<td>Term (months)</td>
<td>t</td>
<td>120</td>
<td>Common loan term for small business equipment (U.S. Small Business Administration)</td>
</tr>
<tr>
<td>Contingency (capital)</td>
<td>$c</td>
<td>10%</td>
<td>(R. Caffey, pers. comm. November 20, 2015)</td>
</tr>
<tr>
<td>Contingency (operating)</td>
<td>$o</td>
<td>10%</td>
<td>(R. Caffey, pers. comm. November 20, 2015)</td>
</tr>
<tr>
<td>Bait Deliveries Per year</td>
<td>$n</td>
<td>$n = 12 (4 deliveries per month)</td>
<td>Based on current bait storage life (up to 5 days refrigerated)</td>
</tr>
<tr>
<td>Bait Delivery Miles</td>
<td>$m</td>
<td>Variable</td>
<td>Calculated. $m = $n • selected route distance</td>
</tr>
<tr>
<td>Shrimp Pickups Per Year</td>
<td>$p</td>
<td>6, 12, or 24</td>
<td>Based on estimated freezer storage space</td>
</tr>
<tr>
<td>Shrimp Pickup Miles</td>
<td>$p</td>
<td>Variable</td>
<td>0 if incorporated into deliveries (if separate from deliveries, $p = $a * round trip miles to shrimp pickup location)</td>
</tr>
</tbody>
</table>
(Table 3.3 continued)

<table>
<thead>
<tr>
<th>Variable Description</th>
<th>Variable</th>
<th>Assumptions</th>
<th>Source/Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport cost ($/mile)</td>
<td>T</td>
<td>$1.703 per mile</td>
<td>Average annual trucking cost per mile, including permitting, insurance, fuel, and maintenance (Torrey and Murray 2015)</td>
</tr>
<tr>
<td>Annual Bait Delivery and Shrimp Pickup (miles)</td>
<td>T&lt;sub&gt;a&lt;/sub&gt;</td>
<td>Variable</td>
<td>Calculated. T = 1.703 • (D&lt;sub&gt;m&lt;/sub&gt; + P&lt;sub&gt;m&lt;/sub&gt;)</td>
</tr>
<tr>
<td>Cooler electricity usage (kWh/yr)</td>
<td>E&lt;sub&gt;r&lt;/sub&gt;</td>
<td>7,920 (small), 13,200 (medium), 30,000 (large)</td>
<td>Based on calculations of electricity use by various walk-in coolers estimates</td>
</tr>
<tr>
<td>Freezer electricity usage (kWh/yr)</td>
<td>E&lt;sub&gt;f&lt;/sub&gt;</td>
<td>Equal to cooler operating cost</td>
<td>Based on calculations of electricity use by various walk-in freezer estimates</td>
</tr>
<tr>
<td>Other electricity usage (kwh/yr)</td>
<td>E&lt;sub:o&lt;/sub&gt;</td>
<td>25 kWh for all equipment running during labor hours</td>
<td>Based on total labor hours</td>
</tr>
<tr>
<td>Total Electricity (kwh/yr)</td>
<td>E</td>
<td>Variable</td>
<td>Calculated. E = E&lt;sub&gt;r&lt;/sub&gt; + E&lt;sub&gt;f&lt;/sub&gt; + E&lt;sub:o&lt;/sub&gt;</td>
</tr>
<tr>
<td>Electricity Cost ($/kwh)</td>
<td>E&lt;sub&gt;c&lt;/sub&gt;</td>
<td>$0.0866/kWh</td>
<td>Based on average Louisiana commercial energy use (US EIA, 2015)</td>
</tr>
<tr>
<td>Labor weeks per year</td>
<td>L&lt;sub&gt;w&lt;/sub&gt;</td>
<td>45</td>
<td>Assummes holidays, vacations, and other days off</td>
</tr>
<tr>
<td>Worker Productivity (baits/day)</td>
<td>L&lt;sub&gt;p&lt;/sub&gt;</td>
<td>1,000-3,000</td>
<td>Variable</td>
</tr>
<tr>
<td>Part-time Labor (days/week)</td>
<td>L&lt;sub&gt;d&lt;/sub&gt;</td>
<td>3</td>
<td>Variable</td>
</tr>
<tr>
<td>Part-time labor hours (per day)</td>
<td>L&lt;sub&gt;h&lt;/sub&gt;</td>
<td>8</td>
<td>Common factory workday</td>
</tr>
<tr>
<td>Part-time Labor cost ($/hr)</td>
<td>L&lt;sub&gt;c&lt;/sub&gt;</td>
<td>$10</td>
<td>Common wage for factory workers</td>
</tr>
<tr>
<td>Derived labor units - year</td>
<td>L&lt;sub&gt;u&lt;/sub&gt;</td>
<td>Variable</td>
<td>Calculated. L&lt;sub&gt;u&lt;/sub&gt; = Q ÷ L&lt;sub&gt;p&lt;/sub&gt;</td>
</tr>
</tbody>
</table>

After calculating costs associated with TFC and TVC, I performed a sensitivity analysis of shrimp-alginate feasibility by simulating various production scenarios in a template-based budget in Microsoft Excel, as is the industry standard for preliminary budgeting.
Using the following formulas, I generated outputs for each of the key budgeting parameters: total annual costs (TAC), total (projected) annual revenue (TAR), breakeven cost (BE), and net revenue (to owner):

\[
TAC = TVC + TFC
\]
\[
TAR = S_a \cdot P
\]
\[
NRO = TAR - TAC
\]
\[
BE = \frac{TAC}{Q}
\]

With every model parameter change in the template, I generated a new set of values for TAC, TAR, NRO, and BE.

To evaluate trends in breakeven cost (BE) and total (projected) annual revenue (TAR), I modified one model parameter at a time while keeping all other parameters constant. The focal parameters used to determine the main drivers of annual costs were sales (%), worker productivity, and bait delivery/shrimp pickup miles. I recorded trends in BE price point and net revenue to owner (NRO) after many iterations of single parameter modifications, after which I altered assumptions to establish how best to reduce costs below the competitive threshold of $0.30/ bait unit, equivalent to the current cost of one bait unit of menhaden.

3.3 Results

3.3.1 Analysis Based on Current Bait Characteristics

Sensitivity analysis of bait production scenarios ranged significantly with changing assumptions. Increasing production scale showed economic benefits in all cases. To illustrate the most realistic manufacturing scenario if the bait supply line were
operating today, I made mostly conservative assumptions including low annual sales (50%), low worker productivity (1,000 baits/days), small bait delivery area to large cities only (397 miles), weekly bait delivery schedule (48x/year), and no shrimp pickup schedule (0x/year, assumed to be included in bait delivery area). Although chemical costs per bait did not change considerably with increasing volume ($0.14 for small production, $0.13 for medium and large), breakeven cost (BE) decreased with shifts in production volume. With unit bait price set at the $0.30 threshold, the most conservative assumptions of small production showed a $0.51 BE cost, far higher than the $0.30 desired threshold that represents the current cost of menhaden. For medium production (1.5 million bait units), BE dropped to $0.37 and under large production (3.0 million bait units), BE decreased to $0.34. In all three cases, net revenue to owner was negative, and the desired bait price threshold was exceeded by the breakeven cost.

Comparing proportional operating costs under conservative conditions highlighted trends also evident when I altered operating assumptions. For all conservative scenarios, contingency remained the same (9%). Electricity cost was smallest of all annual operating costs, and at most took up 3% of annual operating costs. Under small production operating conditions, transportation costs made up a large portion of annual operating costs, whereas the proportion decreased considerably for medium (11%) and large (5%) production models. Chemical costs were a large proportion of variable costs for all three scenarios, as was labor (Figure 3.2).
Figure 3.2. Percentage of annual operating costs for small (a), medium (b), and large (c) production scenarios simulated with conservative assumptions.

Alteration of assumptions for each production scenario showed that increasing worker efficiency from 1,000 to 3,000 baits per day would dramatically cut down the proportional operating cost of labor. For small production, tripling worker efficiency dropped the proportion of labor cost from 21% to 8% of annual operating expenses. In the medium production scenario, labor dropped from 43% to 21%, and for large production labor cost reduced from 38% to 18%. Concurrent with reductions in the proportion of labor cost were increases in the proportion of chemical costs, and as chemical cost is constant with all assumptions, economic benefits are greatest where chemical costs account for the majority of operating expenses.

Reducing breakeven cost below the $0.30/bait unit threshold required specific adjustments to each production scale scenario. At the small production scale, reaching a below-threshold BE price per bait unit required extremely liberal assumptions. Only if the small producer reached 100% annual sales, delivered only locally (delivery miles = 0, shrimp pickups = 134 miles, 6x per year), and had high worker efficiency (3,000 baits/person/day) did the BE drop low enough, with a price of $0.23 per bait unit. At the medium production scale, a BE of 0.24/bait was possible with 75% sales, medium
worker efficiency (2,000 baits/day) and deliveries to large coastal cities that include the shrimp pickup location. With high worker efficiency, BE dropped to $0.22/bait, and with 100% sales, BE reduced an additional $0.02 for medium production. For the large production scenario, reducing BE below $0.30 per unit was more realistic, as a BE cost of $0.27 was possible with low worker efficiency and 75% sales. Increasing worker efficiency further increased the BE estimate to $0.20 per bait unit.

3.3.2 Analysis Based on Future Bait Modifications

For shrimp-alginate bait, high refrigeration and transportation costs are a function of brief bait shelf stability. Currently bait must be refrigerated during the hardening process and stored until used (within 5 days). Refrigerator storage costs make up between one quarter and half of the capital costs in all production volume scenarios, and large volume refrigeration increases electricity use. Because the bait must be used quickly, weekly deliveries are necessary.

I modified production assumptions to speculate the impact of month-long shelf stability on operating and capital costs. I made liberal assumption for these models, including high worker efficiency (3,000 baits/person/day), 100% bait sales, no refrigeration start-up or operating costs, and monthly bait deliveries to large coastal cities that include the shrimp pickup location. I found that for all three scenarios, the largest proportion of operating costs shifted to chemicals (already fixed for each production volume) and revenue to the owner increased (Figure 3.3).
In the speculative small production scenario, BE cost dropped to $0.23 per bait, and total annual revenue to the owner was $20,701. Although the revenue from bait production alone probably would not support an owner-operator’s annual living expenses, it may sufficiently bolster the wages garnered by the entire business. In the speculative medium production scenario, BE dropped to $0.17 per bait and net annual revenue to the owner increased to $190,282, and in the large production scenario BE remained at $0.17 per bait and net revenue to the owner increased substantially ($404,362). In each of these scenarios, bait could be sold between 23% and 43% lower than menhaden at the $0.50/lb. threshold.

3.4 Discussion

Direct comparison of shrimp-alginate bait production to that of other alternative formulated baits is not currently possible because sales and revenue information is lacking. For both formulated and natural baits, market bait prices are often available but are not indicative of trends in breakeven cost or total annual revenue. One formulated alginate bait has been manufactured for the eel and conch fisheries, however their sales and revenue information is not publicly accessible. Despite being unable to compare
shrimp-alginate to other similar business, sensitivity analyses based on a partial budgeting approach was a useful tool for looking at shrimp-alginate bait feasibility. Partial budgeting has been used for evaluating changes to other Louisiana fisheries, including direct marketing of shrimp (Christoferson 2015). However, unlike shrimp direct marketing, many of the assumptions made for bait analysis were hypothetical, based on estimates derived from scaling up laboratory bait production. Under the current bait manufacturing scenarios, production of shrimp-alginate bait is less feasible at small scales of production unless sales and worker efficiency are very high, and only as long as the bait is produced and consumed locally. Although this situation is technically possible, it would require that many fishermen in a single location switch from their current bait to shrimp-alginate immediately after production begins. Strong marketing tactics may improve the chances of high sales in a local area, however none are currently in place. Therefore the success of shrimp-alginate in the bait market would be more likely with large production volume. Concurrently, any new supply lines must exhibit moderately high efficiency from the start of operation.

Although I looked at bait efficacy with independent and commercial field tests, a direct relationship between bait efficiency and bait feasibility was not made because I did not record weights of crab catch and per-pound value of various crab size classes. In other bait research, bait-to-catch ratios have been used to evaluate efficiency and subsequently determine ratios of yield (by weight) to bait cost (McClain and D’Abramo 2006, Harnish and Willison 2009), and in the future, a direct comparison of crab yield by weight and bait use by weight could shed light on the expected cost returns by different bait types.
Determining the willingness for fishermen to pay for new bait was not assessed in this study, although previous survey results (Anderson 2014) show that fishermen would purchase bait if it performed as well or better than traditional baits. The majority of respondents said they would only try a new bait if costs were less than the current bait, while several replied that they would also try it for the same price as conventional bait (Anderson 2014). Repeating and expanding fishermen surveys throughout the region would benefit this research tremendously, as it would reduce potential discrepancies between perceived willingness to pay for bait and actual inclination to use the new bait. The Colorado recreational rainbow trout (Oncorhynchus mykiss) fishery experienced this issue with a trout stocking program that yielded a considerable discrepancy between the money spent stocking trout and the economic benefits realized from fishing (Johnson et al. 1995). Surveys of crab fishermen regarding bait use may prevent such discrepancies before money is invested in a new supply line.

Breakeven cost analysis for each of the manufacturing designs showed that reducing the price of bait to a level that increases profits for fishermen (i.e. below $0.30/bait unit) is not yet possible with conservative sales assumptions, unless a large volume manufacturer begins production with high efficiency. Conversely, if a manufacturer begins with low efficiency (expected for new business operations) and experiences high initial sales, crab fishermen would improve profits and the supply line may thrive. Reduction in breakeven cost is certainly possible with significant improvements to alginate bait, and could be re-evaluated with a different approach to the analysis. Although I based each production volume scenario on a percentage of the bait market demand, analyses could instead be structured around scenarios in which...
the sale prices of baits are predetermined. For example, a shrimp aquaculture feasibility analysis in Brazil created scenarios based on percent reductions in the average price of shrimp, feed, and water costs (Valenti et al. 2011). This approach could be taken with shrimp-alginate production after an accurate production line has been priced out. Regardless of analysis format, more catch data, formula modification, and experimentation with producing bait in a manufacturing setting would bolster this bait research. Several federal grants, including the Marine Fisheries Initiative (MARFIN), Small Business Research Initiative (SBIR), and the Saltonstall-Kennedy Grant Program could each be applicable to progress research with shrimp-alginate bait.

Brief shelf life directly impacts projected storage and transportation costs for shrimp-alginate bait in all manufacturing scenarios, as refrigerated storage must be large enough to hold a week's supply of bait at any time, and weekly transportation is required to keep bait fresh. Running sensitivity analyses with modified liberal assumptions showed that increasing shelf stability to one month would reduce operating expenses (transportation and electricity) and capital costs as well as reduce the necessary selling price $0.06 to $0.13 per bait below the current price of menhaden. The Lively Laboratory (LSU) is currently investigating effects of additional preservatives on shrimp-alginate shelf life. If successful, shelf life extension would increase the feasibility of producing shrimp-alginate bait at all production levels.

3.5 Works Cited


APPENDIX B: COMMERCIAL SAMPLING – BARATARIA 1
APPENDIX C: COMMERCIAL SAMPLING - MUD LAKE 1

Trap Arrangement in Lower Mud Lake - July 15, 2015
Cameron Parish, LA

Lower Mud Lake Traps
Bait Type and Trap Count
- Menhaden 36
- Shrimp 54

Map Prepared by Elizabeth Clages
Coordinate System NAD83 UTM Zone 13N

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community
APPENDIX D: COMMERCIAL SAMPLING – DULAC 1

Trap Arrangement in Bayous near Dulac, LA - July 22, 2015

Dulac Traps
Bait Type and Trap Count
- Menhaden 171
- Shrimp 45
APPENDIX H: SHRIMP-ALGINATE BAIT PREPARATION

Scogin HV Alginate Matrix Formulation
• Standard bait size is 440 ml

Dry Chemicals Needed for Alginate (% of dry ingredients):
• Scogin HV (47%)
• Sodium Bicarbonate (NaHCO₃) (21%)
• Citric Acid (C₆H₈O₇) (21%)
• Ascorbic Acid (C₆H₈O₆) (11%)

Quantities:

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Weight Percent</th>
<th>1 L Alginate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scogin HV</td>
<td>2%</td>
<td>20g</td>
</tr>
<tr>
<td>Sodium Bicarbonate (NaHCO₃)</td>
<td>0.9%</td>
<td>9g</td>
</tr>
<tr>
<td>Citric Acid (C₆H₈O₇)</td>
<td>0.9%</td>
<td>9g</td>
</tr>
<tr>
<td>Ascorbic Acid (C₆H₈O₆)</td>
<td>0.5%</td>
<td>4.6g</td>
</tr>
<tr>
<td>Room temperature DI H₂O (20-25 °C)</td>
<td>47.8%</td>
<td>478g</td>
</tr>
<tr>
<td>Heated DI H₂O (70-90 °C)</td>
<td>47.8%</td>
<td>478g</td>
</tr>
</tbody>
</table>

Alginate Solution Preparation:
1) Put room temperature DI H₂O in mixing container
2) Start drill with mixer attachment at the bottom center of the container
3) Slowly add the Sodium Bicarbonate, Citric & Ascorbic Acids to the container and mix for 2 minutes
4) Add heated DI H₂O and mix well
5) Make sure drill is creating a vortex and slowly add Scogin in the direction of the vortex to ensure complete mixing
6) Move drill around in container to ensure top, bottom and all sides are equally mixed. Solution will become more viscous as it is mixed
7) Mix for ~ 15 minutes or until the surface becomes glassy which indicates mixing is complete
8) Pour finished mixture into holding container with lid (if necessary) and refrigerate until ready to use

Attractant Preparation:
1) Place thawed shrimp heads in a food processor until a paste forms
Bait Preparation:

Quantities:

<table>
<thead>
<tr>
<th>Compound</th>
<th>Weight Percent</th>
<th>440 ml = 1 bait</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attractant</td>
<td>24%</td>
<td>100 ml: 105g</td>
</tr>
<tr>
<td>Alginate Solution</td>
<td>67%</td>
<td>300 ml: 292 g</td>
</tr>
<tr>
<td>Calcium sulfate (7.11% solution)</td>
<td>9%</td>
<td>40 ml: 37 g</td>
</tr>
</tbody>
</table>

1) Pour alginate into bait mixing container
2) Add appropriate amount of attractant to alginate
   a. Ratio = 1:3 (Attractant: Alginate)
3) Mix with drill to ensure complete mixing of attractant and alginate
4) Add Calcium Sulfate to bait mixing container and quickly mix thoroughly
5) Allow bait to set-up approximately 5 minutes

Final Bait:

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Weight Percent</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scogin HV</td>
<td>1.34%</td>
<td>Alginate</td>
</tr>
<tr>
<td>Sodium Bicarbonate (NaHCO₃)</td>
<td>0.61%</td>
<td></td>
</tr>
<tr>
<td>Citric Acid (C₆H₈O₇)</td>
<td>0.61%</td>
<td></td>
</tr>
<tr>
<td>Ascorbic Acid (C₆H₈O₆)</td>
<td>0.34%</td>
<td></td>
</tr>
<tr>
<td>DI H₂O (20-25 °C)</td>
<td>64.3%</td>
<td></td>
</tr>
<tr>
<td>Attractant</td>
<td>24%</td>
<td>Shrimp Paste</td>
</tr>
<tr>
<td>Calcium sulfate</td>
<td>9%</td>
<td>Hardener</td>
</tr>
</tbody>
</table>
APPENDIX I: LABORATORY SCALE BAIT PREPARATION DIAGRAM

Phase 1: Alginate Preparation

Drill or drum mixer

Mixing bit

Mixing container or large drum

H₂O

Ca(H₂PO₄)

Ca(H₂CO₃)

H₂O

Heated Alginate Acid

Alginate mixture
Phase 2: Incorporation of Attractant

Alginate mixture in small container

Phase 3: Incorporation of Calcium Hardener

Shrimp Alginate Mixture

1 min set time
ElizaBeth L. Clowes was born in Youngstown, Ohio. She graduated from Ursuline High School in 2009 and Ohio University Honors Tutorial College in 2013 with a degree in Biological Sciences and a certificate in Environmental Studies. Following graduation she worked as a field technician and crew leader for the Diamondback Terrapin Monitoring Project on Poplar Island in the Chesapeake Bay, Maryland. She went on to pursue a master’s degree under the direction of Dr. Julie Anderson Lively at Louisiana State University in Baton Rouge, Louisiana. Throughout her year and a half long field season plagued by boat motor issues, she successfully returned to shore each trip without requiring a tow.