Assessment of the Value of Shellfish Aquaculture in the Gulf of Mexico as Habitat for Commercial and Recreational Fish Species

Prepared for

Auburn University School of Fisheries, Aquaculture and Aquatic Sciences and Alabama Cooperative Extension

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Dr. John Supan, Louisiana Sea Grant College Program, LSU Agricultural Center, Louisiana State University

Abbreviations

kg	Kilogram
lbs	Pounds
m^2	Square meters
NMFS	National Marine Fisheries Service
RUM	Random Utility Model

Executive Summary

The purpose of this study is to evaluate the value of habitat in economic terms provided by off-bottom adjustable long line Eastern oyster (*Crassostrea virginica*) aquaculture in the Gulf of Mexico. The term habitat "value," when pertaining to fishery resources, is defined as a habitat's ability to support or enhance a fishery resource. Consequently, the greater the abundance and diversity of fish in a particular habitat, the greater its habitat value (Able, 1999). This work is part of a larger study looking at the economic value of ecosystem services of off-bottom oyster farming as offsets to regulatory fees. The study is being overseen by Dr. William Walton at Auburn University Shellfish Lab and Dr. John Supan of Louisiana Sea Grant College Program, Louisiana State University. Their project is in reaction to the regulatory hurdles to the establishment of oyster aquaculture in the Gulf of Mexico region. They posit that if these challenges can be addressed, significant investment and subsequent establishment of a substantial oyster farming industry within the region can be anticipated.

While the literature is still relatively limited, a number of studies have shown that shellfish farms provide enhanced habitat value for the fish that frequent them (Ulanowicz and Tuttle, 1992; Dealteris et al., 2004a; O'Beirn et al., 2004; Ferraro and Cole, 2007; Powers et al., 2007; Tallman and Forrester, 2007; Clynick et al., 2008; D'Amours et al., 2008; Erbland and Ozbay, 2008; Marenghi and Ozbay, 2010). Using market analysis for commercial fisheries and benefits transfer for recreational fisheries, we estimate the economic value of enhancement of selected fisheries from habitat provided by off-bottom oyster aquaculture in Alabama and Louisiana.

In Alabama, current farms (including farmer training areas) located in Portersville Bay are approximately 50 acres (Figure 2).[1] In Louisiana, the Grand Isle Oyster Farming Zone is 25 acres (Figure 3). In both cases, species that use the oyster bags as refuge from predation include blennies, gobies, juvenile snapper (gray and lane), shrimp, blue crabs, mud crabs (xanthidae), and stone crabs. Species attracted to the long lines include sea trout, red drum, black drum, sheepshead, flounder, catfish, and mullet. Of these, fish species of commercial importance include shrimp and blue crab. Species of recreational importance include red drum, sea trout, flounder, snapper, sheepshead, blue crab, and shrimp. According to Reault (2013), long line oyster aquaculture sites (caged oysters) represent the same hard substrate as oyster and shell on reef do. Their current aquaculture sites are in close proximity to several oyster reefs and oyster restoration projects and thus share similar biophysical characteristics. Given the similarity between off-bottom oyster aquaculture sites and oyster reefs, in order to assess the benefits of habitat provided by long line oyster aquaculture at sites in Louisiana and Alabama, we use abundance enhancement effects for specific fish species summarized in Kroeger (2012), whose research focuses on oyster reef restoration.

The harvestable production enhancement of fished species that is expected to result from current in the water long line oyster aquaculture parks in Louisiana and Alabama is 8,876 and 11,361 kilograms per year respectively. Using the market price method we estimate the change in commercial fisheries values associated with long line aquaculture parks in Louisiana and Alabama to be $14,144 and $7,987 per year respectively. Using the benefits transfer method we estimate the change in recreational fisheries values to be $43,011 and $42,063 per year respectively.

[1] Total site footprint is 50 acres, consisting of 24 acres to be used for commercial culture and 8 acres for research. Therefore, 50 acres is the total potential size. It is projected that by the end of 2013 there will be 12 acres and by the end of 2014, 12-50 acres.

Our analysis illustrates the positive external benefits resulting from the habitat provided by Gulf of Mexico off-bottom long line aquaculture parks in terms of enhancements to important commercial and recreational fisheries in the region. The potential value of this additional habitat within the two oyster farming parks analyzed is approximately $22,000 per year in commercial and $85,000 per year in recreational fisheries enhancements. We estimate the marginal economic value per acre of off-bottom long line aquaculture in terms of recreational and commercial fisheries enhancements in Alabama and Louisiana to be $1,564 and $2,286 respectively. While there are most certainly limitations to our methodological approach this analysis does illustrate the potential positive externalities of such technology above and beyond the market value of their oyster production.

1 Introduction

The purpose of this study is to evaluate the value of habitat in economic terms provided by long line Eastern oyster (*Crassostrea virginica*) aquaculture in the Gulf of Mexico. The term habitat "value", when pertaining to fishery resources, is defined as a habitat's ability to support or enhance a fishery resource. Consequently, the greater the abundance and diversity of fish in a particular habitat, the greater its habitat value (Able, 1999). This work is part of a larger study looking at the economic value of ecosystem services of off-bottom oyster farming as offsets to regulatory fees. The study is being overseen by Dr. William Walton at Auburn University Shellfish Lab and Dr. John Supan of Louisiana Sea Grant College Program, Louisiana State University. Their project is in reaction to the regulatory hurdles to the establishment of oyster aquaculture in the Gulf of Mexico region. They posit that if these challenges can be addressed, significant investment and subsequent establishment of a substantial oyster farming industry within the region can be anticipated.

In Alabama, a newly permitted 60-acre oyster farm park in Portersville Bay has been established. At a minimum, the program will train and start-up twelve farmers over the next two to three years. Community members have suggested that the park will soon reach capacity and discussions have begun about potential expansion of the park and/or creation of new parks in other locations along the Alabama coast. In addition to the park, two other commercial oyster farms have been fully permitted and are in operation: Point aux Pins Oyster Farm and Mobile Oyster Company have been established in Alabama, with sales in a number of states at high-end restaurants. These oysters have been featured at a number of Alabama seafood promotional events. Permit applications are pending for several others.

In Louisiana (where the Louisiana Sea Grant Program's Oyster Research and Demonstration Farm has been in operation for the past 12 years), the 2012 Louisiana Legislature passed Act 583, which created a 25-acre oyster farming zone, administered by the Grand Isle Port Commission, and Act 293, defining Alternative Oyster Culture and allowing the use of the water column and surface over existing oyster leases currently totaling over 300,000 acres. The Grand Isle Oyster Farming Zone includes eight 2-acre parcels with surrounding 40-ft navigation lanes. A private commercial off-bottom oyster farm, Caminada Bay Oyster Company, began production in 2011, including operation of an on-shore nursery system that attracted numerous visitors during its inaugural season. Off-bottom oyster farming is gaining interest, while state agencies are beginning to include oyster farm parks in their coastal planning. Currently, the Louisiana Department of Wildlife and Fisheries is permitting Alternative Oyster Culture on oyster leases located within a suitability map, a product of marine spatial planning study that attempts to reconcile user conflicts that might arise with off-bottom systems. In addition, the Mississippi Marine Resources Department recently inquired about the potential for off-bottom oyster farming in the region. Furthermore, the primary investigators have received inquiries about the feasibility and permitting of oyster farms in Texas and Florida, and hosted a site visit in summer 2011 by Florida Sea Grant agents, regulators, and seafood industry members, as well as presented information at numerous workshops in Florida.

In this analysis, based on a large body of literature that suggests there exists a positive role of shellfish aquaculture in the attraction of fish and invertebrates (see Section 2.1), we assume that there is a positive correlation between the habitat provided by oyster off-bottom aquaculture and harvestable fish species. Increases in such habitat will lead to an increase in harvestable fish stocks in the region, which, in turn, will lead to higher catch rates and value in local commercial and recreational fisheries. Given similarities between existing experimental aquaculture sites and local oyster reef restoration projects in Louisiana and Alabama, and lack of fisheries enhancement data specific to aquaculture, we estimate the value of oyster aquaculture habitat using existing data related to oyster reefs.

2 Literature Review

This section first reviews studies that describe the effects of shellfish aquaculture on fishery species habitat and on populations of those species. Next, the section reviews studies that have used economic valuation methods to express in monetary terms the value of shellfish aquaculture as fisheries species habitat.

2.1 Ecological Effects

Most of the literature evaluating the role of shellfish as habitat for fisheries species focuses on the value of natural and restored shellfish beds, especially oyster reefs. While several studies have investigated the environmental effects of shellfish aquaculture, reviews of these studies show that most have concentrated on the influence of suspended bivalve culture on the benthic environment, generally concentrating on the physical, chemical, and biological processes occurring in the sediments (Kaiser, 2001; Dumbauld et al., 2009; Forrest et al., 2009; McKindsey et al., 2011; Shumway, 2011; Cranford et al., 2012). Oyster shell forms a three-dimensional emergent, complex, firm substrate with a variety of microhabitats for use by resident macrofauna (Harding and Mann 1999, 2001; Lenihan, 1999; Glancy et al., 2003; Dealteris et al., 2004b; Grabowski et al., 2012b). In many estuarine systems, this ecotope is increasingly rare and in many cases is limiting for associated populations of fishes (Lehnert and Allen 2002, Posey et al. 1999). Firm substrate provides shelter from predators (McDonald 1982) (Coen et al., 2007; Coen and Grizzle, 2007). Red drum *Sciaenops ocellatus*, larvae had lower mortality in mesocosms containing simulated oyster reefs compared with other habitat types (Stunz and Minello 2001). Shell also attracts a unique assemblage of epifauna and fouling organisms that in turn provide food. Oyster shell serves as spawning substrate for skilletfish (Runyan, 1961), Florida blenny Chasmodes saburrae (Peters, 1981), feather blenny Hypsoblennius hentz (Breitburg, 1999) and frillfin goby Bathygobius soporator (Peters, 1983). Comparatively few studies have yet sought to quantify secondary production attributable to shellfish aquaculture.

In order to be able to draw on the larger body of literature describing natural and restored populations, it is helpful to examine the similarities and differences between shellfish aquaculture and natural or restored shellfish beds or reef communities (Coen et al., 2011). The complex structures formed by some species of bivalve shellfish such as oysters and mussels represent a temperate analog to coral reefs that occur in more tropical environments (Lenihan and Grabowski, 1998; Harding and Mann, 1999). Both kinds of structures are “biogenic”, being formed by the accumulation of colonial animals, and both provide complex physical structure and surface area used by scores of other species as a temporary or permanent habitat (Brumbaugh et al., 2006). The extensive irregular surfaces of an oyster reef provide 50 times the surface area of a similar sized flat bottom. This three-dimensional emergent, complex, firm substrate creates a variety of microhabitats for use by resident macrofauna (Lenihan, 1999; Harding and Mann, 2001; Glancy et al., 2003; Grabowski et al., 2012a). These crevices provide good nursery habitat for a wide diversity of vertebrate and invertebrate organisms—worms, snails, sea squirts, sponges, crabs, and fish (Henderson and O’Neil, 2003). By overcoming a survival bottleneck in the early life history of many fish and invertebrate species, oyster reefs enhance recruitment in those species; alternatively, oyster reef habitat enhances survival and subsidizes growth of individuals already present in the regional population by providing refuge from predation and access to reef-associated prey resources (Peterson et al., 2003; Coen et al., 2007; Coen and Grizzle, 2007). Many studies have documented the utilization of oyster reefs for refuge and foraging by finfish and decapod crustaceans in estuarine systems (e.g, Breitburg, 1999; Coen et al., 1999; Harding and Mann, 1999; Posey et al., 1999; Harding and Mann, 2001; Peterson et al., 2003; Luckenbach et al., 2005; Tolley and Volety, 2005; Rodney and Paynter, 2006; Scyphers et al., 2011).

If oyster reefs (Figure 1) and coral reefs are similar in terms of their structural heterogeneity and vertical relief, shellfish aquaculture operations can be considered to function more or less as do artificial reefs (McKindsey et al., 2006; Tallman and Forrester, 2007). As with wild oyster reefs, the physical structures used in shellfish aquaculture (racks, cages, nets, ropes, trays and lines) provide habitat by providing surfaces for attachment of fouling organisms that in turn become forage for fish and other predators (Shumway et al., 2003; Tallman and Forrester, 2007). In addition, macroalgae and epifauna growing upwards from protective plastic mesh used in bottom clam culture can substitute for natural seagrass habitat as a nursery area for mobile invertebrates and juvenile fish. Coen et al. (2007) found that in comparison to unplanted adjacent sandflat, the epibiotic habitat growing on aquaculture bottom netting had a 42 (fenced lease) to 46 (open lease)-fold enhancement of mobile invertebrates and a 3 (fenced lease) to 7 (open lease)-fold enhancement of juvenile fishes. Even the plastic mesh used over planted clams develops epiphytic growth and vertical structure similar to eelgrass, supporting similar assemblages of mobile fish and crustaceans (Powers et al., 2007). In addition, the subtidal rack and bag systems used to rear oysters in Southern New England and parts of the Northeast can act as refugia for a variety of marine organisms, including the juvenile stages of various species of commercially valuable finfish (Rice, 2008).

Figure 1. Off-bottom Aquaculture System, Alabama

Source: NOAA 2014

While the literature is still relatively limited, a number of studies have shown that shellfish farms provide enhanced habitat value for the fish that frequent them (Ulanowicz and Tuttle, 1992; Dealteris et al., 2004a; O'Beirn et al., 2004; Ferraro and Cole, 2007; Powers et al., 2007; Tallman and

Forrester, 2007; Clynick et al., 2008; D'Amours et al., 2008; Erbland and Ozbay, 2008; Marenghi and Ozbay, 2010). The fish that aggregate in aquaculture gear tend to survive better and grow as fast or faster. Whether shellfish aquaculture attracts fish and invertebrates or produces them is likely an issue of continuum, with each species in the target community responding differently and each population having potentially different responses (Marenghi and Ozbay, 2010).

One of the key distinctions between natural reef structures and oyster aquaculture is that the farmer periodically tends the gear to control biofouling, maintain optimal stocking densities, and eventually harvest the market-size animals. The frequency of this maintenance varies greatly depending on gear types, seasons, fouling intensity, and husbandry practices. From a practical standpoint, the typical farmer is only able to tend a small fraction of his gear at any given time. Typically the farmer works his gear in rotation on a 1–3 month cycle, meaning that some of his gear may be clean, but the majority of the gear is typically laden with varying amounts of fouling organisms. The impact of these pulse disturbances tend to be short-term and potentially analogous to storm events in natural systems; and the communities involved tend to be highly adapted to periodic disturbance (Dumbauld et al., 2009).

2.2 Economic Valuation Studies

A few studies have used economic valuation methods to express in monetary terms the value of shellfish aquaculture as fisheries species habitat. Peterson et al. (2003) reviewed available empirical data on quantitative improvement of nekton populations by restoring oyster reefs in the southeast United States and applied demographic and growth models to estimate the species-specific augmentation of fish and crustacean production that is expected per unit area of oyster reef restoration. They estimated that 10 square meters (m^2) of restored oyster reef yielded an additional 2.6 kilograms (kg) per year (2,600 kg per hectare per year) of production of fish and large mobile crustaceans for the functional lifetime of the reef. Grabowski and Peterson (2007) converted the amount of augmented production per each of the species groups that were augmented by oyster reef habitat in Peterson et al. (2003) to a commercial fish landing value. According to the researchers, for fish of commercial significance, the enhanced production by the reefs equates to $3,700 per hectare per year and, over a 50-year time span, the fish productivity would exceed the anticipated value of directed oyster harvest from the same area by more than 34 percent.

A study in North Carolina (West Bay, Neuse River) by Lenihan and Grabowski (1998) compared the value of fish and crab from three oyster reefs to the value of harvest from adjacent unstructured sand bottom areas. A total of 15 commercially valuable species were found to utilize restored oyster reef habitat. The study results indicated that the long-term commercial value of these fish and crabs was greater than the value of the oyster production.

Recreational anglers who are aware of the species variety and abundance of fish available over oyster reefs value the reefs for the enhanced recreational fishing opportunities they provide. Isaacs et al. (2004) employed the contingent valuation method to estimate the value of Louisiana's oyster reefs as recreational fishing grounds, using a sample drawn from resident saltwater anglers who participated in the National Marine Fisheries Service's Marine Recreational Fishing Statistical Survey. A telephone survey was conducted featuring a dichotomous-choice net willingness to pay question. The average annual net willingness to pay among resident saltwater recreational fishermen to maintain access to recreational fishing over Louisiana's oyster reefs was $13.21. Gulf of Mexico Ecosystem Service Data Base Henderson and O'Neil (2003) estimated the recreational value of oyster reefs using willingness to pay at $15.46 (2008 dollars) per person per year and $2,340,000 per year. NOAA (2014) estimated recreational values using willingness to pay in Louisiana at $5.64 (2008 dollars) per hectare per year and $16.10 (2008 dollars) per person.

Kroeger (2012) developed estimates of the net economic benefits of two oyster reef restoration projects in Mobile Bay, Alabama. The author first developed total annual production enhancement estimates of selected species from oyster reefs in Mobile Bay based on findings reported in Scyphers et al. (2011), and Peterson et al. (2003). He then calculated that the two reefs, which have a combined project length of 3.64 miles, would lead to additional fish and crab harvests of approximately 6,900 pounds (lb) per year. This additional catch would generate profits for harvesters, processors, wholesalers, distributors, retailers, and restaurants, and net economic benefits for consumers, both from seafood consumption and recreational fishing. Kroeger used the benefit transfer method to estimate the total consumer surplus the two reefs are expected to provide to recreational anglers. He drew on the results of eight existing studies to develop willingness to pay estimates for specific individual species or broader groups of fish that together cover most of the species enhanced by oyster reefs in the northern Gulf of Mexico. The total net economic benefits to the commercial and recreational fishing sectors were estimated to be between $37,800 and $46,200 per year.

3 Methods

The economic concept of value has been broadly defined as any net change in human well-being or welfare. In economic analysis, any action which increases welfare is a benefit and any action which decreases welfare is a cost. As discussed above, the structure provided by shellfish aquaculture serves as habitat for species of fish and crustaceans. This improvement may ultimately lead to measurable increases in the production of additional types of finfish and invertebrates targeted in commercial and recreational fisheries. Larger populations of important commercial and recreational species potentially mean significant contributions to economic welfare in the form of greater industry revenues and consumer benefits. More explicitly, economic welfare includes what economists call consumer surplus and producer surplus. Consumer surplus is the net value consumers receive from a good or service over and above what they actually pay for the good or service. Producer surplus (also called economic rent) is the difference between what producers actually receive when selling a product and the amount they would be willing to accept for the product. While not an exact measure of social welfare, the sum of the consumer and producer surplus that results from an increase in the abundance of economically important stocks of fish and crustaceans provides a useful approximation of the value of shellfish aquaculture as fisheries species habitat.

Economists typically think in terms of both market and non-market goods and services and apply different approaches to assess their value. Market value is measured using supply and demand curves and recognizes the transactions between producers and consumers. On the other hand there are two general types of approaches for estimating economic welfare gains (or losses) of non-market goods and services. The first approach, which is to conduct primary research, can be subdivided into indirect (observed market behavior) and direct (contingent valuation) methods. Indirect approaches rely on behavior in related markets to reveal valuations of non-marketed goods. Economists tend to prefer this method of valuation because data is based on observed market behavior. Indirect methods, or contingent valuation, use survey based methods to ask people to state their willingness-to-pay, or willingness to accept, to derive preferences. Both methods require significant amounts of time and money to extract quality data. Consequently, some researchers have adopted the second approach, commonly called benefits transfer, whereby existing valuation information for an ecosystem service is used to estimate the value of a similar ecosystem service. The selection of a specific approach will likely depend on a combination of factors including financial resources, time frame, and required accuracy of the estimates. The sections below discuss these alternative approaches. However, because of the scope of this analysis and budgetary restrictions we selected the advanced benefits transfer technique given that the literature review revealed a wealth of relatively recent peer reviewed and applicable studies. The sections below discuss these approaches in greater detail.

3.1 Recreational Fishing

3.1.1 Random Utility Models

Primary research is the preferred method for calculating recreational welfare gains and losses when money and time are not dominant limiting factors. The current “gold standard” for primary research is the nested Random Utility Model (RUM), which current peer-reviewed literature indicates provides the most accurate results (Johnston et al. 2005). RUMs are well established as tools for estimating recreation base losses (Hausman et al. 1995; Adamowicz et al. 1994; McFadden 1995; Desvousges et al. 1996; Adamowicz et al., 1997). Random utility theory states that the angler chooses a fishing trip from a set of trips that have varying attributes (e.g., target catch rate, non-target catch rate, species targets available, travel cost, location, distance, bag limits, companions, etc.). The angler selects the trip that will maximize her utility for that given experience. RUMs created to model recreational fishing demand can use data from several types of studies including the travel cost methodology.[2]

Stated Preference Data

Conjoint stated preference data are collected by asking survey respondents to choose between a series of hypothetical trip options described by trip attributes such as those described above. The quality of the attributes (e.g., different catch rates, species, etc.) varies between paired choices. The advantage of conjoint stated preference data is that they can be collected quickly from anglers without having to have them record actual trip data. However, studies have indicated that both conjoint and contingent valuation forms of stated preference are likely to overestimate values, particularly those associated with emotional issues (National Research Council, 2004; Cummings and Taylor, 1999). For a more detailed example of a conjoint stated preference study on recreational fishing in the Gulf of Mexico area please see Gentner (2004), Oh and Ditton (2003), Haab et al. (2000). Gentner (2004) may be a particularly relevant example for designing a RUM utilizing conjoint stated preference data. The study is based in the area of concern, and the experimental design of this study includes varying attributes for species, bag limits, and catch rates, while also allowing for the effect on utility of catching non-target species. It is important for the experimental design to include both bag limits and catch rates, because a reduction in catch rates may not necessarily mean a reduction in bag limits when anglers routinely catch more fish than they're allowed to keep.

Revealed Preference Data

Revealed preference data are derived from asking anglers to track their fishing behavior over a period of time. Their behavior reveals their preferences for the attributes associated with fishing experiences. The benefit of revealed preference data is that they accurately reflect the real-world behavior of anglers. However, the data collection for these efforts takes time, they are expensive to conduct correctly, and the survey instrument must accurately track site and trip information for the data to provide accurate estimates. Additionally, the data are subject to real-world variations such as uncharacteristic weather or other random events, which can effect variation. For example, a revealed preference survey of Gulf of Mexico fishing that occurred in the months following Hurricane Katrina would be unlikely to accurately reflect long-term preferences, because anglers would be unlikely to have had the full suite of options normally available to them. It can also be more difficult to gauge angler reactions to policy changes with revealed preference data as the policy changes can be built directly into stated preference survey instruments, which allows anglers to react to them directly.

[2] For a more detailed description of the RUM see Hensher et al. (2003) or in the context of recreational fishing please see Haab et al. (2000); Gentner (2004).

Benefits Transfer

Benefits transfer methods have been around for a number of years and are generally considered to be inferior to primary research methods. That said, when applied appropriately, they can represent a set of reasonable estimation methods when factors constrain financial, data, and/or temporal resources. Benefits transfer methods come in several forms including:

- Direct transfer of benefits estimates from a single study to a target analysis
- The transfer of values which have been aggregated or adjusted based on expert opinion
- The estimation of values by a model utilizing site data from multiple studies using relevant and comparable site data (Bergstrom and De Civita, 1999)

The value transfer uses summary measures of the environmental benefit estimates directly (Dumas et al., 2005). The approach encompass the transfer of a single (point) benefit estimate from an existing study, or a measure of central tendency for several benefit estimates from a previous study or studies (such as an average value). The primary steps to performing a single point estimate transfer include identifying and quantifying the changes in, say, recreational use at a study site, and locating and transferring a "unit" consumer surplus measure (Rosenberger and Loomis, 2001). Consequently, this approach is well suited for this situation where the projected impacts of fishery enhancement can be measured in fairly homogeneous, divisible units (Ready and Navrud, 2005).

We apply the first of these benefits transfer options using estimates for individual relevant species in Louisiana and Alabama to derive recreational fishing values associated with habitat related stock enhancements from long-line off bottom oyster aquaculture.

3.2 Commercial Fishing

The common methodology for estimating the commercial fishing-related benefits to society from shellfish aquaculture is the market price method. The market price method uses the prices of goods and services that are bought and sold in commercial markets to determine the value of an ecosystem service (King and Mazzotta, 2000). By measuring the change in producer and consumer surplus after the application of a change in production or price, the value can be determined (Carson and Bergstrom, 2003).

Welfare received by society from commercial fishing activities is generally represented by profits to the harvesters of the product and willingness to pay by consumers of the harvested product over and above actual expenditures. Profits to the fishermen are referred to as producer surplus, while willingness to pay by consumers over and above expenditures is referred to as consumer surplus. For this analysis, it was assumed that shellfish aquaculture would not affect the commercial catch landing price, but would affect the quantity of fish harvested at that price. As a result, the analysis focused on the increase in producer surplus as the measure of societal benefit in the commercial fishing sector. Net benefits were assessed as the product of an estimated net benefits ratio for each species and region-specific fishery, multiplied by the gross revenue from increased commercial fishing harvest.

We use this approach to assess the commercial fishery enhancements related to habitat provided by long line oyster aquaculture parks in Alabama and Louisiana.

4 Analysis

To assess the benefits of habitat provided by long line oyster aquaculture parks in Louisiana and Alabama, we use abundance enhancement effects for specific species summarized in Kroeger (2012). Two types of enhancements effects exist—those that are derived by enhancing survival of reef-associated species that use the aquaculture structure to seek refuge from predation, and those that increase the abundance of both highly and less-highly reef-dependent species by enhancing recruitment. Kroeger's enhancement effects are derived using various studies analyzing the abundance of specific species and crustacea in areas of oyster reef restoration versus those of sedimentary bottom aquaculture (Peterson et al. [2003] and Scyphers et al. [2011]—See Appendix A).

Net social welfare or value is calculated for commercial fisheries using market information and recreational fisheries using non-market estimates from the literature and benefits transfer.

4.1 Site Characteristic

In Alabama current farms (including farmer training areas) located in Portersville Bay are approximately 50 acres (Figure 2). In Louisiana, the Grand Isle Oyster Farming Zone is 25 acres (Figure 3). In both cases, species that use the oyster bags as refuge from predation include blennies, gobies, juvenile snapper (gray and lane), shrimp, blue crabs, mud crabs (xanthidae), and stone crabs. Species attracted to the long lines include sea trout, red drum, black drum, sheepshead, flounder, catfish, and mullet.

According to Reault (2013) long line oyster aquaculture sites (caged oysters) represent the same hard substrate as oyster and shell on reef do. Their experimental sites are close in proximity to oyster reefs and oyster restoration projects used by Kroeger (2012) and thus share similar biophysical characteristics. Site characteristics for the two experimental projects are illustrated in Table 1.

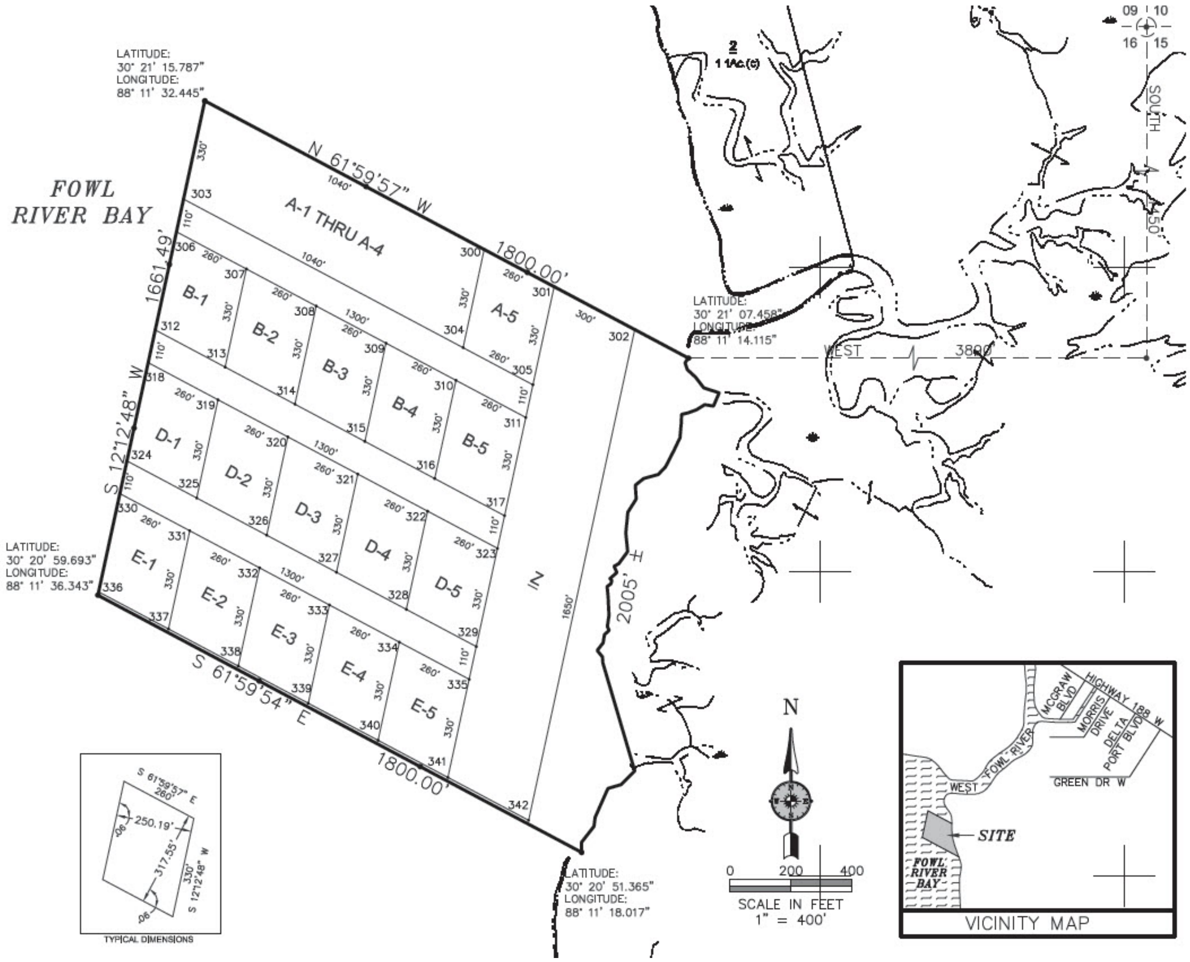
Table 1. Off-bottom Aquaculture Site Characteristics

Characteristic	Grand Isle, LA	Portersville Bay, AL
temperature (ºC)	17-32	10-32
salinity (ppt)	10-30	10-28
bottom substrate	sand	Muddy Sand
tidal current	High	Very Low
water depth (ft)	4-8	3-6
distance from shore (ft)	500	1,800
total acres	25	32[3]
total project footprint (top view)	101,172 m^2	202,343 m^2

Source: Walton 2013; Supan 2013

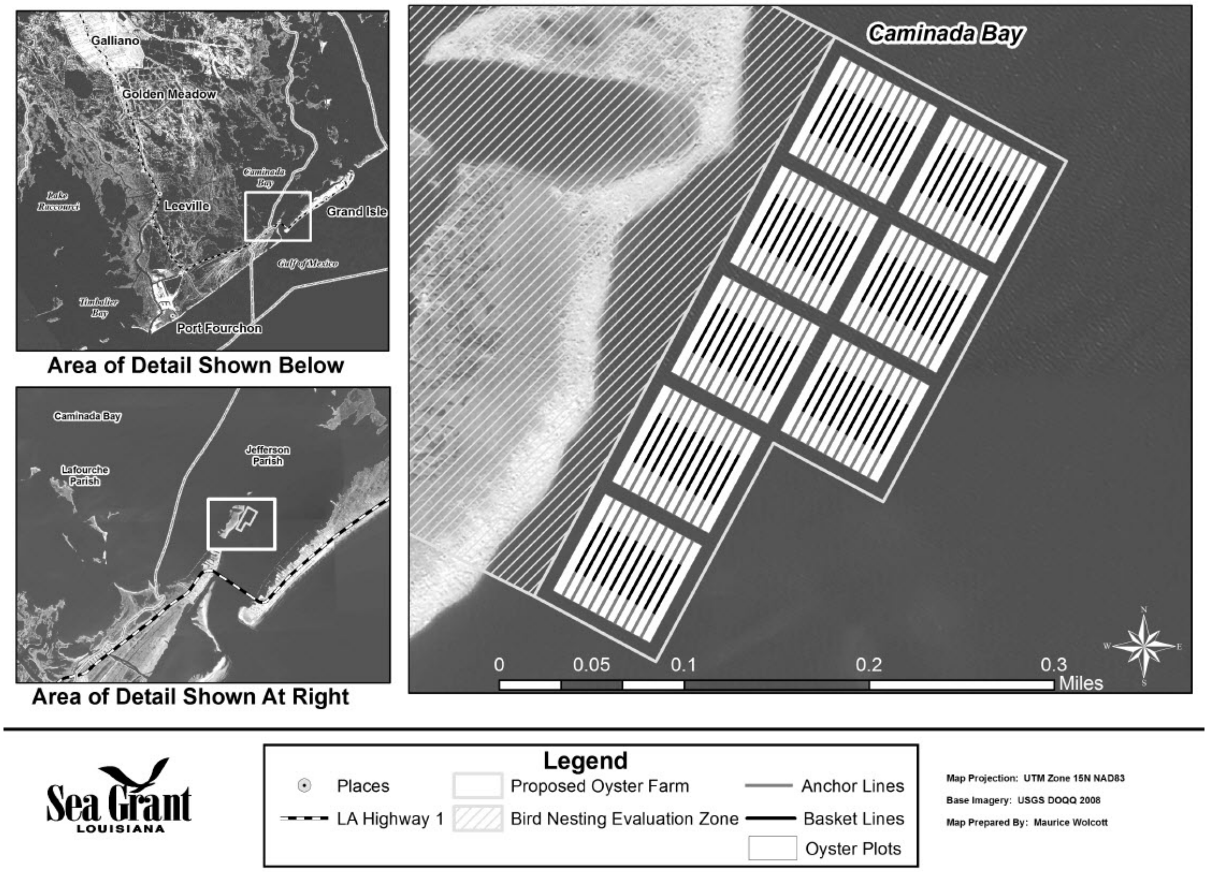
[3] Total site footprint is 50 acres, consisting of 24 acres to be used for commercial culture and 8 acres for research. Therefore, 32 acres is the total potential size of the fully developed area and the number used further in our analysis.

Figure 2. Proposed Portersville Bay Oyster Farming Zone, Alabama



Source: Walton 2014

Figure 3. Proposed Grand Isle Oyster Farming Zone, Louisiana



Source: Louisiana Sea Grant 2013

4.2 Fishery Enhancement

Comparing these site characteristics and species' attraction and use to those outlined in Kroeger (2012) we feel it is justifiable to use data related to fishery enhancement from restored oyster reefs in Mobile Bay, Alabama as described in that report. Their assessment, based on Peterson et al (2003) and Scyphers et al (2011) looked at the estimated increase in production of fish and large mobile crustaceans due to the enhancement effects of oyster reefs (see Appendix A).

Using our estimate of enhanced density in each age class, we quantified how much annual production each age class would be expected to achieve, and summed these production estimates over all ages to estimate total annual enhanced production for each species (Peterson et al. 2003). An important assumption made by Peterson et al. 2003 is that the 0 year-class recruits, assessed in most studies at an age of approximately one-half year, would all survive to their first birthday. This overestimates annual production by assuming all fish survive between their half birthday and first birthday. The overestimate is assumed to compensate for the failure to adjust estimates of production for those other fish in that same age class that had recruited to the reefs and grew to some size but died before sampling occurred on the half birthday. For Gobbies and Blennies, annual enhancement was calculated by multiplying average fish weight by the estimate of density enhancement. The remaining four species were calculated using the von Bertalanffy growth equation. The three species located at the bottom of the list were not calculated in Peterson et al. (2003), but were included due to the possibility of production enhancements existing for those species.

Scyphers et al. (2011) calculated enhancement effects for those species not covered in Peterson et al. (2003). Those species, listed in Appendix A, were evaluated at two young breakwater reefs in Mobile Bay that were constructed of loose oyster shell. Abundance results were calculated by comparing the fish and shellfish abundance and community composition between the reef sites and those observed at nearby control (mud/sand bottom) sites. Because Scyphers et al. (2011) did not report mean weights for each species, estimates were converted to absolute production enhancement values to compare results found in Peterson et al. (2003).

Using production enhancements reported in Peterson et al. (2003) and Scyphers et al. (2011), multiplied by the appropriate site characteristics, estimated an increase in production of 73,460 kg/yr. Table 2 lists each species' potential production enhancement given long line Eastern oyster aquaculture at each proposed site in the Gulf of Mexico. For species listed in the top half for which total enhancement (all sizes) is listed, enhancement calculations include all size classes. For those species listed in the bottom half, enhancement is only estimated for those species within the 5-10cm class size. The difference lies in alternative methods used between Peterson et al. (2003) and Scyphers et al. (2011).

Table 2. Estimated Enhancement of Annual Production of Selected Species by State

Species	Production enhancement, kg/yr	
	Louisiana	**Alabama**
Species for which total enhancement (all size classes) is estimated		
Gobies	6,515	8,340
Blennies	506	647
Sheepshead	5,929	7,589
Stone crab	6,606	8,456
Gray snapper	1,153	1,476
Silversides (mullet)	20	26
Species for which only enhancement of the 5cm/10cm mesh size fraction is quantified:		
Black drum	34	44
Blue crab	2,315	2,963
Red drum	254	325
Spotted seatrout	540	692
Sand seatrout	460	589
Southern flounder	153	196
Total, all species	24,487	31,343
Total, fished species *	17,465	22,356

Notes: Rows 1-12 based on Peterson et al.'s production enhancement estimates (Table 2) multiplied by respective reef area (Table 1); rows 13-20 based on production enhancement estimates in Table 4 multiplied by respective reef area (Table 1). * Excludes gobies and blennies.

Source: Kroeger (2012) with updated data from Northern Economics, Inc.

However, it is not assumed that all estimated species enhancements will reach harvestable size. To adjust the total species enhancements shown in the top half of Table 2, Kroeger (2012) calculates the percentage of each species' total production enhancement that is accounted for by specimens of below-harvestable size. Therefore, the harvestable portion for each species is determined by those specimens that are within a certain size range. Table 3 outlines the suitable harvest enhancement for each species at each restoration site. The harvestable production enhancement of fished species that is expected to result from long line oyster parks in Louisiana and Alabama is 20,237 kg/year.

Table 3. Estimated Annual Enhancement of Harvestable Production of Selected Species by State

	Production enhancement, kg/yr	
Species	**Louisiana**	**Alabama**
Gobies	Not fished	Not fished
Blennies	Not fished	Not fished
Sheepshead	2,846	3,643
Stone crab	1,453	1,860
Gray snapper	819	1,048
Silversides (mullet)	1	2
Black drum	34	44
Blue crab	2,315	2,963
Red drum	254	325
Spotted seatrout	540	692
Sand seatrout	460	589
Southern flounder	153	196
Total, harvestable specimens	**8,876**	**11,361**

Notes: Rows 1-12 based on Peterson et al.'s production enhancement estimates (Table 2) adjusted with below-harvest age classes excluded, and multiplied by respective reef area (Table 1); rows 13-20 based on production enhancement estimates in Table 4 multiplied by respective reef area (Table 1).

Source: Kroeger (2012) with updated data from Northern Economics, Inc.

4.3 Recreational and Commercial Fishing

2012 harvest of commercially important species in Alabama and Louisiana outlined in this study are presented in Table 4 and Table 5. Commercial harvest data are reported by the National Marine Fisheries Service (NMFS), unless otherwise noted below. Recreational harvest data were reported by the Marine Recreational Fisheries Statistics Survey in 2012. To apportion additional harvest volumes to recreational and commercial fisheries, the percentage of commercial harvest share was calculated for 2012. Using this method of apportionment, this section will identify the potential value associated with additional harvest volumes for both user groups.

Table 4. 2012 Recreational and commercial landings in Alabama of Select Fish Species

Species	Recreational harvest, lb	Commercial landings, lb	Commercial share (%)
Black drum	75,679	68,537	48
Red drum	589,140	No harvest *	0
Sand seatrout	117,606	31,508	21
Spotted seatrout	61,787	No harvest **	0
Southern flounder	6,946	n/d	~30#
Silversides (mullet)	130,622	1,943,933	94
Sheepshead	658,813	123,002	16
Gray snapper	10,553	488	4
Blue crab	See text	See text	80##
Stone crab	See text	See text	25

Notes: * Commercial red drum fishery still closed in 2012. **Game fish only status (Alabama Department of Conservation and Natural Resources, 2012). #Average of commercial catch share in Louisiana (around 10 percent on average during 1996-2002; Stevens, 2004) and Texas (around 50 percent since the late 1980s). ##Tatum (1982).

Sources: Kroeger (2012) with updated data from Northern Economics, Inc.

Table 5. 2012 Recreational and Commercial Landings in Louisiana of Select Fish Species

Species	Recreational harvest, lb	Commercial landings, lb	Commercial share (%)
Black drum	4,279	4,169,820	100
Red drum	289,972	No harvest *	0
Sand seatrout	28,311	1,772	6
Spotted seatrout	1,143,074	98	0
Southern flounder	10,826	97,043	90
Silversides (mullet)	2,696	1,393,665	100
Sheepshead	8,623	738,358	99
Gray snapper	419,369	32,039	7
Blue crab	See text	See text	80##
Stone crab	See text	See text	25

Notes: * Commercial red drum fishery still closed in 2012. ##Tatum (1982).

Sources: Kroeger (2012) with updated data from Northern Economics, Inc.

Kroeger (2012) reports that NMFS does not collect data on recreational crab harvest. Recreational blue crab harvest in Alabama was conservatively estimated to be 20 percent of commercial harvest (Tatum, 1982), which is within the range of estimates reported for other Gulf States (Perry and McIlwain, 1986; Jordan et al., 2008). This estimate is applied to both Alabama and Louisiana blue crab harvest. Additionally, Kroeger (2012) assigns 75 percent of stone crab to recreational fisherman based on discussions with local fishermen who suggest most local stone crab harvest is used for personal consumption. Kroeger does not specify "local" fisherman, and also uses the estimate for both areas of long line oyster aquaculture production.

4.3.1 Recreational Fishery Valuation

Using the method outlined above, total additional recreational harvest between the two aquaculture sites could reach over 23,000 lbs per year, as shown in Table 6. Notice that unit measurement of additional harvest volumes is now presented in pounds to better align with the units presented in studies used to calculate economic values.

Table 6. Estimated Annual Increase in Recreational Catch by State, lb/yr

Species	Alabama	Louisiana	Total
Sheepshead	5,287	93	5,379
Stone crab	2,403	3,076	5,479
Gray snapper	1,726	2,147	3,872
Silversides (mullet)	0	0	0
Southern flounder	236	43	279
Black drum	40	0	40
Blue crab	1,021	1,306	2,327
Red drum	560	717	1,276
Spotted seatrout	1,191	1,524	2,715
Sand seatrout	800	1,222	2,023
Total	**13,263**	**10,129**	**23,392**

Notes: Based on total harvestable biomass enhancement as shown in Table 6, reduced by species-specific commercial catch share as shown in Table 7.

Source: Kroeger (2012) with updated data from Northern Economics, Inc.

Table 7 presents the marginal recreational values per fish used in the analysis. The recreational welfare gain from shellfish aquaculture is estimated by multiplying the marginal value per fish by the additional number of fish caught by recreational anglers. The average weight of each species was derived from NMFS Recreational Fishery Statistics database and used to determine the total number of additional units (fish) using total enhancement figures in Table 6. Findings estimate an additional $85,000 in welfare gain due to increased recreational harvest.

Table 7. Estimated Increase in Value of Recreational Catch from Oyster Aquaculture Parks

Species	Marginal value per unit (2012$)	Average weight of species	Unit of value	Source	Total value AL (2012$)	Total value LA (2012$)	Total value (2012$)
Sheepshead	4.52	2.5	per expected additional fish caught*	McConnell et al. (1994)	9,558	168	9,726
Stone crab			n/a (no studies available)				
Gray snapper	24.92	3.0	additional fish caught & kept	Haab et al. (2009)	14,333	17,833	32,166
Black drum	4.52	1.4	per expected additional fish caught*	McConnell et al. (1994)	128	0	129
Blue crab			n/a (no studies available)				
Red drum	13.56	4.0	additional fish caught & kept	Haab et al. (2009)	1,898	2,429	4,327
Spotted seatrout	7.43	1.3	additional fish caught & kept	Haab et al. (2009)	6,807	8,713	15,520
Sand seatrout	4.52	0.4	per expected additional fish caught*	McConnell et al. (1994)	9,045	13,814	22,859
Southern flounder	1.99	1.6	per expected additional fish caught*	McConnell et al. (1994)	293	54	347
Total					42,063	43,011	85,074

Notes: *McConnell et al. estimate the consumer surplus of the probability of catching an expected additional 1/2 fish on average per day for two months. With an average of 0.82 trips per two-month period taken by their study population, this is equivalent to catching an additional 0.41 fish. We therefore divided McConnell et al.'s CS/unit values by 0.41 to derive the value per additional fish caught. [1]Assumes all fish caught are kept (avg. weight is 3 lb). [2]Assumes all fish caught are kept (avg. weight is 4 lb). [3]Assumes all fish caught are kept (avg. weight is 1.3 lb). Estimated recreational biomass enhancement of each species due to the two reefs converted to numbers of fish based on available data on numbers and weight of recreational catch by species in Alabama, obtained through queries of NMFS Recreational Fishery Statistics Catch database (http://www.st.nmfs.noaa.gov/st1/recreational/queries/catch/snapshot.html): sheepshead, 2.5 lb; gray snapper, 3.0 lb; black drum, 1.4 lb; red drum, 4.0 lb; spotted seatrout, 1.3 lb; sand seatrout, 0.4 lb; southern flounder, 1.6 lb.

Source: Kroeger (2012) with updated data from Northern Economics, Inc.

4.3.2 Commercial Fishery Valuation

The total commercial value increased harvest of enhanced species across both Louisiana and Alabama is over $22,000 per year. Our estimates use ex-vessel prices, as shown in Table 8 and Table 9, multiplied by estimated increase in commercial landings for each species. Because the areas of the potential off-bottom oyster aquaculture sites are currently commercially fished, and no data were available on the profit margins of local fisherman, it is assumed revenues from additional harvest will translate directly into increased producer surplus (profit).

Table 8. Dockside Prices and Value of Increased Commercial Landings of Fish Species Enhanced by Aquaculture Parks (2012$), Alabama

Species	Enhanced commercial landings, lb/yr	Dockside price, $/lb	Total dockside value of enhanced landings, 2012$
Sheepshead	987	0.64	632
Stone crab	3,204	4.52*	3,621
Gray snapper	1,805	2.0	160
Silversides (mullet)	3	0.62	2
Black drum	76	0.27	10
Blue crab	5,103	0.79	3,225
Red drum	n/a	n/a	n/a
Spotted seatrout	n/a	n/a	n/a
Sand seatrout	1,015	0.63	135
Southern flounder	337	2.00§	202
Total	**12,531**		**7,987**

Notes: Commercial landings estimates based on share of species' production enhancement assumed to be harvested commercially (Table 7). * Dockside price per pound of claws. Stone crab landings weight is reduced by 80% to calculate ex-vessel value of stone crabs. Price for stone crabs is from Louisiana as no data are available for Alabama. §Price for "flatfish" class. No data on price for southern flounder.

Source: Kroeger (2012) with updated data from Northern Economics, Inc.

Table 9. Dockside Prices and Value of Increased Commercial Landings of Fish Species Enhanced by Aquaculture Parks (2012$), Louisiana

Species	Enhanced commercial landings, lb/yr	Dockside price, $/lb	Total dockside value of enhanced landings, 2012$
Sheepshead	7,938	0.42	3,334
Stone crab	1,025	4.52*	4,635
Gray snapper	164	2.59	425
Silversides (mullet)	4	0.70	3
Black drum	97	0.81	79
Blue crab	5,226	0.94	4,912
Red drum	n/a	n/a	n/a
Spotted seatrout	0	2.81	0
Sand seatrout	77	0.77	59
Southern flounder	388	1.80	698
Total	**14,918**		**14,144**

Notes: Commercial landings estimates based on share of species' production enhancement assumed to be harvested commercially (Table 7). * Dockside price per pound of claws. Stone crab landings weight is reduced by 80% to calculate ex-vessel value of stone crabs.

Source: Kroeger (2012) with updated data from Northern Economics, Inc.

5 Discussion

Our analysis illustrates the positive external benefits resulting from the habitat provided by Gulf of Mexico off-bottom long line aquaculture in terms of enhancements to important commercial and recreational fisheries in the region. The potential value of this additional habitat within the two oyster farming parks is approximately $22,000 per year in commercial fisheries and $85,000 per year in recreational fisheries enhancements. We estimate the marginal economic value per acre of off-bottom long line aquaculture in terms of recreational and commercial fisheries enhancements in Alabama and Louisiana to be $1,564 and $2,286, respectively. This value is, of course, in addition to the value of the oyster aquaculture production itself.

Our analysis, however, has a number of limitations, not the least of which reflects the considerable uncertainty regarding the actual impacts shellfish aquaculture has on stocks of commercial and recreational importance. The difficulty of valuing changes in ecosystem goods or services is compounded by the underlying complexity of natural ecosystems, which creates a barrier to quantifying the links from ecosystem structure and functions to the goods and services that people value. The ability of economists to place economic values on ecosystem services is contingent on a concerted effort to measure and document these services in the field. Consequently, ecological uncertainty propagates through to uncertainty about economic outcomes (Dorrough et al., 2008). The current analysis would be greatly enhanced by further biological and ecological studies of the use of aquaculture technologies by fish species of importance in situ.

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Appendix A

Estimated increase in production of fish and large mobile crustaceans due to enhancement effect of oyster reef, based on Peterson et al (2003)

Species	Fish production enhancement (Table 5)	Increase in production kg/yr/10m^2 of reef
Gobies	Yes	0.644
Blennies	Yes	0.050
Sheepshead	Yes	0.586
Stone crab	Yes	0.653
Gray snapper	Yes	0.114
Silversides (mullet)	Yes	0.002
Southern flounder	*Yes**	*n/a*
Red drum (redfish)	*Possibly^*	*n/a*
Speckled seatrout	*Possibly^*	*n/a*

Notes: No estimates of production gains were developed for species in italics because they are not found in Peterson et al.'s (2003) area of interest (Tampa Bay, FL). *Enhancement factor of 1-3.3. ^ Contradictory results in studies; may depend on differences in life stages of individuals in samples.
Source: Peterson et al. (2003)

Commercially or recreationally fished species with the highest abundance enhancement from oyster reefs compared to control sites, as found on two two-year reefs in Mobile Bay

Species	Abundance Enhancement (%)
Black drum	325
Blue crab	297
Silver perch	199
Red drum	108
Atlantic croaker	105
Spotted seatrout**	88
Sand seatrout**	74
Southern flounder	79

Source: Scyphers et al (2011)