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“Green” Clams:
Estimating the Value of Environmental Benefits (Ecosystems Services) Generated by the Hard Clam Aquaculture Industry in Florida

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What are Ecosystem Services?

The millions of species on our planet, including humans, interact with one another in many ways. These interactions among and between species are what define ecosystems. Ecosystems, in turn, provide many environmental benefits or “services” that support human life and well-being. Ecosystem services are the transformation of a set of natural resources (for example, plants and animals, air and water) supplied by ecosystems into beneficial goods and functions that humans value. For example, when fungi, worms, and bacteria transform sunlight, carbon, and nitrogen into fertile soil, this transformation is an ecosystem service provided by those organisms. Scientists know that the value of ecosystem services depends on the resource’s location, necessitating location-specific value estimates for use in informing practical decision-making; decisions, such as: Should we require developers to plant more trees? Should more land be set aside to protect species that generate ecosystem services? If we do destroy or impair ecosystem service functions, how much will it cost us to replace those services? Since public resources are needed to satisfy a variety of community needs, valid estimates of ecosystem services that may be provided or impaired by public policy decisions are necessary.

While ecosystem services are often associated with natural systems, agricultural and aquacultural systems can also provide ecosystem services. Ecosystem services provided by shellfish, for example, are widely reported but usually focus on one ecosystem service and are not well-quantified for most species. Shellfish aquaculture (farming) improves water quality by extracting nutrients, such as nitrogen, and controlling eutrophication. Clearer water reduces turbidity, allowing more sunlight to penetrate, which aids in the growth of important seagrasses and increases oxygen in the coastal environment. By removing phytoplankton and nutrients from the water, shellfish may also help prevent harmful algal blooms. In addition, shellfish convert carbon into calcium carbonate shell, which represents a long-term carbon sink that offsets carbon released from burning of fossil fuels. Thus, shellfish farms may help to mitigate the effects of global warming and climate change that can threaten local coastal economies.

In Florida, the hard clam farming industry supports 540 jobs and produces 125-150 million clams annually, with an economic impact of $39 million in 2012. In addition to the commercial benefits of the hard clam industry from providing fresh shellfish, the farms provide coastal communities with a variety of ecosystem services whose value can be quantified. The results of this study demonstrate the unique sustainability of Florida hard clam aquaculture by providing economic values for ecosystem services provided by the industry; values that can help decision makers decide whether to promote or expand the industry in order to sustain storage, which is

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Thus, these results provide information on the "green" clam industry that is beneficial to growers, wholesalers, retailers, resources managers, and consumers. This paper provides a description of ecosystem services provided by hard clam culture, summarizes value estimates, and relates them to the clam aquaculture industry in Florida.

Ecosystem Services Provided by Shellfish Farming

Ecosystem services are typically grouped into four categories: regulating, supporting, provisioning, and cultural. Bivalves and, therefore, shellfish farms improve water quality and store carbon (a regulating service), are important in nutrient cycling (a supporting service), provide food (a provisioning service), and indirectly support recreation and ecotourism (cultural services), which have tremendous economic value, especially in Florida. This project concentrates on the valuation of regulating and supporting services. Note that estimates already exist for provisioning services (i.e., that the industry generates $39 million in economic impact from clam sales). Estimates for the value of cultural services would require a complex study of behavioral patterns of tourists, which is beyond the scope of this study.

Regulating Services

Regulating services help maintain ecosystem structure by, for example, affecting the climate or maintaining water and air quality. Bivalves (oysters, hard clams, mussels, etc.) contribute to these services simply by feeding. As bivalves feed, they create currents that move water in and out of the animal (Figure 1). Tiny moving cilia (hair-like structures), which cover the gills, pump water through the clam, drawing it in the incurrent siphon. Suspended particles (phytoplankton, microorganisms, and detritus) in the water are captured by the gills and moved to the mouth for ingestion. The cleared water is then ejected from the excurrent siphon. Some of the captured particles may be rejected as "pseudofeces", which are expelled and often fall to the bottom. Therefore, when bivalves "filter feed" they improve water clarity, transfer energy and nutrients from the water column to the benthos (bottom sediments), reduce eutrophication, and potentially reduce harmful algal blooms. The extent of this filter feeding (or "grazing") has been modeled in several locations. For example, in Cherrystone Inlet, Virginia, juvenile hard clams are estimated to filter 10-80% of the tidal creek volume per day. Other researchers have shown that oysters, for example, are capable of removing up to 50% of the annual phytoplankton production in the upper Chesapeake Bay.

Figure 1. Seawater is pumped through the clam by the gills entering and exiting the animal via two siphons.

Shellfish also contribute to carbon sequestration, or storage, which is another regulating ecosystem service. Bivalves convert carbon (C) into calcium carbonate ($CaCO_3$) shell. The carbonate used by bivalves is primarily derived from atmospheric carbon dioxide (CO_2) dissolved in seawater. Carbon stored as shell material can persist on geological time scales. The shells of cultured bivalves, therefore, provide a long-term carbon sink and are of interest as a means to offset carbon released from burning fossil fuels. Preliminary studies of the Florida hard clam industry suggest that each harvested market-sized clam represents almost three grams of mineralized carbon.

Figure 2 shows the role of clams in sequestering carbon in the marine environment. Shellfish not only store carbon in their shells and tissues, but also process it while they are growing. Just like other animals, they produce carbon dioxide as a waste product of respiration. In addition, the carbon (particulate organic carbon, POC) deposited in the sediments as feces and pseudofeces (rejected food particles) is consumed by a variety of organisms, such as worms, brittle stars, and other deposit feeders. Some carbon will remain locked in the sediments and can persist indefinitely as shell fragments, limestone ($CaCO_3$), and dolomite ($CaMg[CO_3]_2$) (i.e., as a carbon sink). In contrast, the carbon

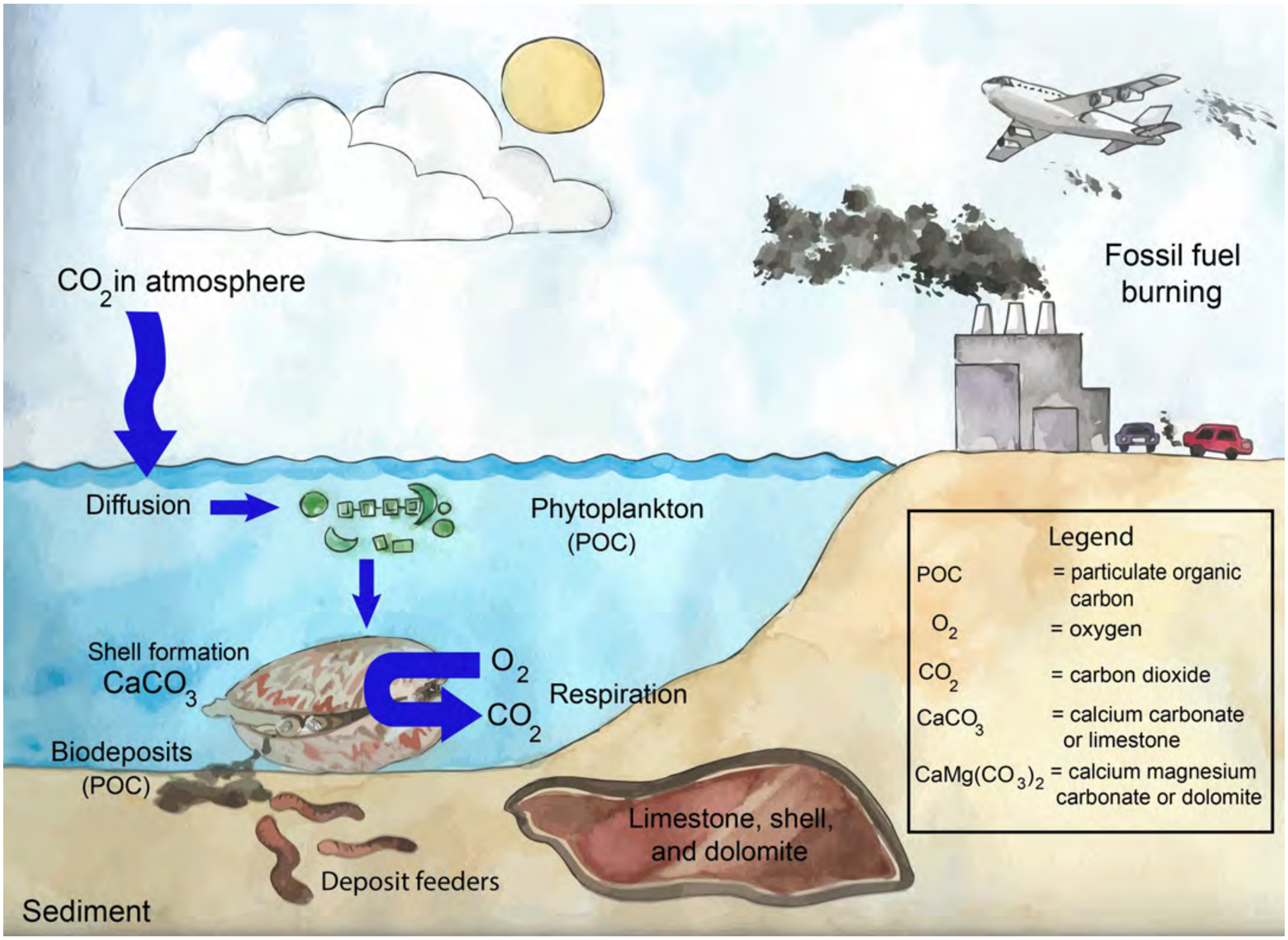

Figure 2. The role of hard clams in sequestering or storing carbon in the marine environment.

contained in most plant and animal tissues returns to carbon dioxide within a few years.

Note that the overall role of nearshore ecosystems and calcifying organisms, such as hard clams, on the carbon cycle is controversial. Bivalves use carbon in two ways — by using dissolved inorganic carbon to build calcium carbonate shell, and by consuming particulate organic carbon as phytoplankton. Bivalves also produce carbon dioxide in two ways — the chemistry of calcium carbonate production apparently releases CO_2, and CO_2 is released as a waste product of metabolic processes, as in other animals. Therefore, shellfish farming has been proposed as both a source and sink of carbon dioxide. However, the role of bivalves in the balance between carbon dioxide emission to, and removal from, coastal waters remains unclear. For example, 10-85% of the carbon used in building shell may originate from the bivalve's own metabolic processes, effectively reducing the total amount of carbon dioxide released by the bivalve from calcium carbonate production and metabolism. In addition, the carbon dioxide released by bivalves, from either process, could be used by phytoplankton in photosynthesis and would, therefore, be recycled within the system. Clearly, there is a need to better understand the role of bivalves in the carbon cycle.

Supporting Services

Supporting services, such as primary production, decomposition, and habitat formation, are necessary for maintaining all other ecosystem services. Bivalves contribute to these supporting services in a variety of ways, including altering nutrient availability through consumption and defecation activities.

Bivalves play an important role in the cycling of nutrients, including nitrogen (N). Bivalves do not absorb nitrogen directly from their environment, rather they feed on naturally-occurring phytoplankton (microscopic algae or plants), which use dissolved

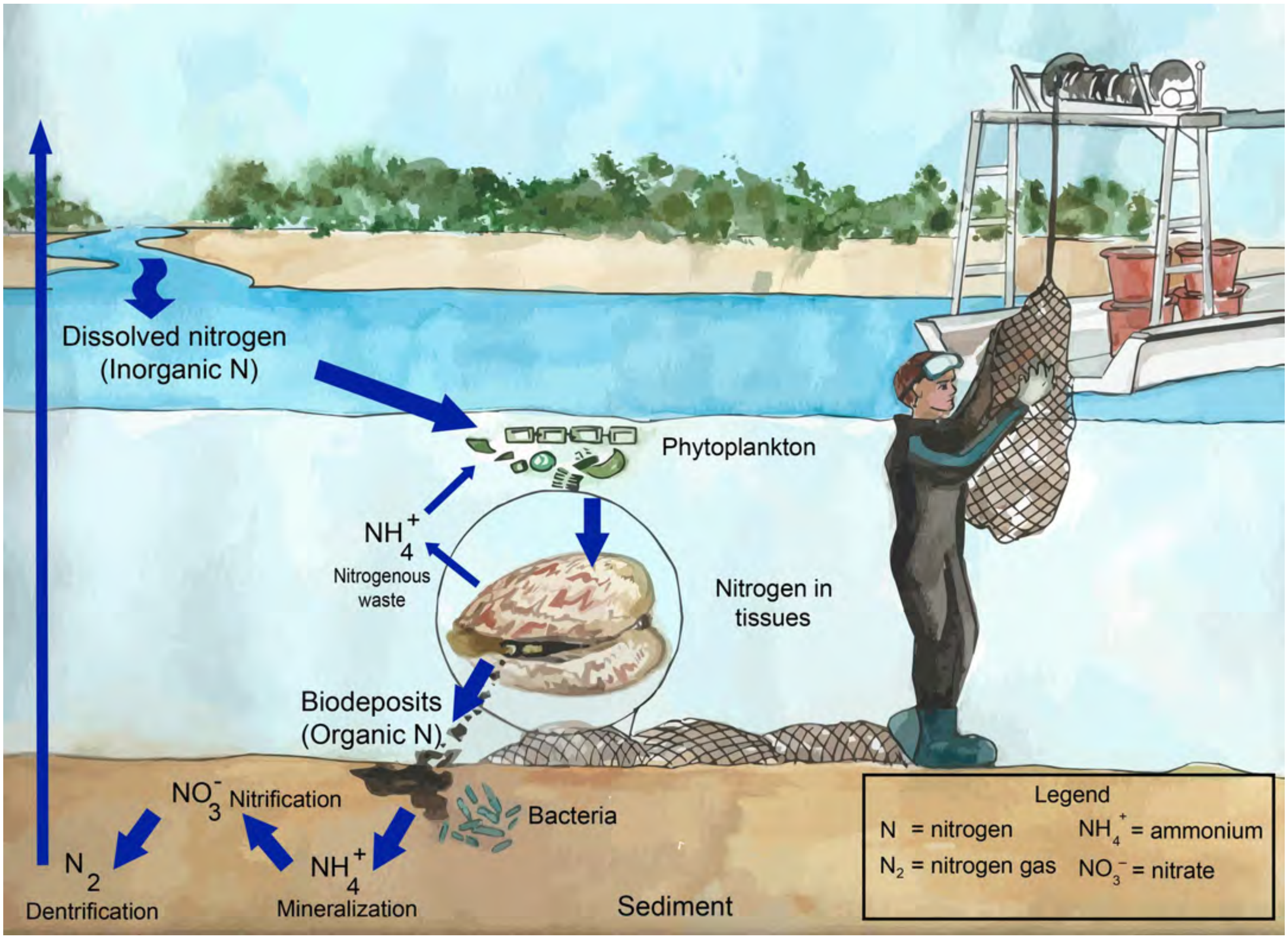

Figure 3. The role of hard clams in cycling and removing dissolved inorganic nitrogen from the marine environment.

inorganic nitrogen, available in the water, to grow. Thus, bivalves incorporate nitrogen from their food into their tissues and shells. When they are harvested, the accumulated nitrogen is removed from the water. In turn, bivalves release nitrogenous waste (urine) that can be used by phytoplankton as a source of nitrogen. In addition, some of the nitrogen filtered from the water by bivalves is deposited to the sediment as feces and pseudofeces (rejected food particles). These biodeposits are decomposed by bacteria. In the well-oxygenated surface sediments, this decomposition produces ammonium ($NH4^{+}$) through mineralization (simply the conversion of nitrogen from an organic to an inorganic form), followed by nitrification (the oxidation of ammonium), forming nitrate ($NO3^{-}$) and nitrite ($NO2^{-}$). Material that is buried in deeper anaerobic sediments (where oxygen is unavailable), undergoes the process of denitrification in which nitrate is reduced and nitrogen gas (N_2) is produced. Figure 3 illustrates how hard clams cycle and remove dissolved inorganic nitrogen from the marine environment.

Note that the development of nitrogen budgets for coastal ecosystems and for bivalve populations is incomplete. This is because nitrogen exists in many different forms, nitrogen cycling is complex, and quantifying nitrogen pathways is technically difficult. However, several models suggest that bivalves remove significant amounts of nitrogen from systems through the combined processes of burial, denitrification, and biomass harvest. A recent model indicates that oyster stocks in the Choptank River, Maryland, are responsible for the removal of 28,660 pounds N annually. Another model shows that a standard sized oyster farm can remove nitrogen at a rate of 40,000 pounds per year while releasing 15,000 pounds per year as excretion and feces, for a net N removal of about 24,000 pounds per year. For comparison, this net removal is equivalent to the untreated waste of over 3,000 people.

Valuation of Ecosystem Services Provided by Shellfish Farming

Several recent studies have focused international attention on the science of valuing ecosystem services and the increased use of ecosystem service information when making critical public decisions. Since ecosystem services provide a variety of benefits naturally to people, communities, and businesses, they essentially provide society with “free goods” that we do not have to pay for. As public goods, such ecosystem services are unpriced and, therefore, are at risk of being lost when ecosystems are lost or degraded. Given the inherent challenges associated with monetizing the value of ecosystem services, the values associated with these ecosystem functions are currently under-represented and do not always receive consideration commensurate with goods and services sold commercially.

There are a number of accepted methods used for estimating the monetary value of ecosystem services. These methods vary in their applicability depending upon the type of benefit being measured, available information, and the certainty of the change in the environment associated with the proposed action. The most common method, known as the replacement cost method, utilizes market information to obtain a conservative estimate of a feasible alternative method of providing the service. With this method, the quantity of ecosystem service is determined by first estimating a bio-physical model (i.e., amount of nitrogen removed or the amount of carbon stored), and then estimating the cost of providing this level of service with a human-made alternative (e.g., a replacement such as a wastewater treatment plant or planting trees). Using net nitrogen removal estimates associated with the standard sized oyster farm reported in the previous section (i.e., 24,000 lb per year), the replacement cost method would seek to determine the cost of processing the untreated waste of approximately 3,000 people annually with a wastewater treatment plant.

Several studies have employed the replacement cost method to determine the value of ecosystem services provided by shellfish production but, to the best of our knowledge, few have considered hard clam production (examples include studies of Manila clams, Kumamoto and Pacific oysters, and mussels). Notable results (with all values converted to U.S. dollars using current conversion rates) include:

- The removal of 25,787 pounds of nitrogen per year by Manila clams, Kumamoto and Pacific oysters, and mussels at a value of $884,400 for the alternative, which is a water treatment plant in Shelton, Washington.
- The removal of 63,640 pounds of nitrogen per year worth about $0.29 million from a Manila clam farm in the southern coast of Portugal; and, the extrapolated removal of over 62 tons of nitrogen per year valued at $5.5 billion provided by all European Union shellfish farms.
- The removal of 23,552 pounds of nitrogen per year from a hypothetical 1.5-acre oyster farm valued at $2.2 million.
- The removal of nitrogen by oyster reefs in the Mission-Aransas estuary in Texas is valued at $113,471 per year.
- Using nitrogen removal rates from oyster reefs off the coast of North Carolina, an acre of oyster reef provides nitrogen removal services valued at $1,640 per year.
- Blue mussel production in eastern Skagerrak, Sweden (1,650 tons of mussels produced annually) is found to remove 16.5 tons of nitrogen valued at $4.40 to $6.55 per pound.
- Salt marshes and mangroves are estimated to sequester carbon that is valued at $12.34 per acre per year.

Clearly, estimates depend on species, location, service (removal of nitrogen and/or carbon) and valuation method used. As such, converting between studies to draw generalizations is complicated, especially if generalizations are not sufficient for policy making.

Ecosystem Services Provided by the Florida Hard Clam Culture Industry

In this study, the unique sustainability of the Florida hard clam aquaculture industry was assessed by examining three environmentally-beneficial ecosystem services (water filtration, nitrogen removal and carbon storage) provided by clam farming. Efforts focused on assembling ecosystem service measurements and values specific to bivalve culture, identifying

Table 1. Water filtration, nitrogen (N) removal, and carbon (C) storage values determined per clam for three commercial size grades of Florida cultured hard clams.

Clam Grade	Shell Width (inches)	Shell Length (inches)	Water Filtration (gallons/day)	N Removed (grams)	C Stored (grams)
Littleneck	1.03	1.88	4.5	0.09	2.76
Button	0.92	1.67	3.5	0.07	1.97
Pasta	0.80	1.49	2.7	0.06	1.37

information gaps for hard clams *Mercenaria mercenaria*, and translating information to Florida's hard clam culture industry. Measurements, particularly for harvest-sized clams at the water temperatures found in Florida, are not available through the literature. To address these information gaps, pertinent laboratory measures were determined and results are summarized in Table 1 and discussed below.

Water Filtration

Shellfish filter phytoplankton (microscopic algae or plants) out of the water when feeding, thereby naturally cleaning and clarifying the water. The filtering rate of clams was measured in the lab using a fiber-optic colorimeter, which measures the turbidity of a phytoplankton solution. The turbidity of the water declined over time, as the clams removed the phytoplankton from the water. Using this data, the volume of seawater cleared of phytoplankton per day for three commercial grades of hard clams was calculated; a littleneck-sized clam was found to filter 4.5 gallons of seawater per day (Table 1).

Nitrogen Removal and Carbon Storage

The amounts of nitrogen and carbon removed from the ecosystem upon harvest were determined by measuring the contents of both clam tissues and shells. Clam tissues and shells were dried, weighed, and ground to fine powders. Stable isotope mass spectrometry was used to determine the proportion of nitrogen and carbon in the sample. From these data, the total weight of nitrogen and carbon in the tissue and shell of each clam was calculated (Table 1); each littleneck-sized clam represented about 0.09 grams of nitrogen and about 2.8 grams of carbon stored in tissue and shell.

Value of Ecosystem Services Provided by the Florida Hard Clam Culture Industry

The contribution of the Florida hard clam industry to the mitigation of nitrogen and carbon extraction was assessed. The costs that would be incurred to replace the industry's services with the next best alternative were calculated. For nitrogen removal, appropriate replacement cost values were based on the costs of wastewater treatment plants in various locations, including the cities of Clearwater and Fort Myers in Florida. These cities were chosen due to their proximity to clam-producing areas and due to limited data availability for other Florida cities. The clam-producing counties were then assigned either the value for Clearwater ($3.44 per pound of nitrogen removed) or Fort Myers ($5.22 per pound of nitrogen removed), based on which location most closely matched the county's land values and cost of living, factors that affect the cost of wastewater treatment plants.

For carbon sequestration, the creation and maintenance of pine tree plantations was used as a possible alternative to hard clam production. Costs included pine production, as well as the value of the land in an alternative use. In counties with high agricultural, commercial, or urban land values, this opportunity cost of utilizing the land as a pine plantation was high. The cost per ton of carbon sequestered was calculated for all clam-producing counties in Florida using previously reported estimates of these variable land use values. The cost included a weighted average of the cost of converting land to forest, where the weights were proportional to the amount of land in a county under crops, pasture, or range. The highest carbon sequestration values ($119.01 per ton) were estimated for Collier County, while the lowest ($0.71 per ton) costs were in Franklin County, primarily due

Table 2. Values of two ecosystem services, nitrogen (N) removal and carbon (C) storage, determined for Florida clam-producing counties.

County	Value of N Removal	Value of C Storage
Brevard	$3.44/lb	$40.64/ton
Charlotte	$3.44/lb	$30.94/ton
Collier	$5.22/lb	$119.01/ton
Dixie	$3.44/lb	$21.95/ton
Franklin	$3.44/lb	$0.71/ton
Indian River	$5.22/lb	$113.39/ton
Lee	$5.22/lb	$97.56/ton
Levy	$3.44/lb	$16.88/ton
Manatee	$3.44/lb	$32.60/ton
St. Johns	$3.44/lb	$24.38/ton
Volusia	$5.22/lb	$65.80/ton
Average	$4.09/lb	$51.26/ton
Median	$3.44/lb	$32.60/ton

to lower land values in the more rural county. Table 2 summarizes the values by county and ecosystem service.

Based on the results of the 2012 Florida aquaculture survey conducted by the U.S. Department of Agriculture, 544 million gallons of seawater per day were filtered by the statewide production of 136 million clams (Figure 4). In turn, 25.4 thousand pounds of nitrogen were removed and 760.6 thousand pounds of carbon were stored through their harvest. The size of clams harvested was determined by surveying several shellfish wholesalers; it was assumed that 75% of the clams harvested were littlenecks or larger, 20% were buttons, and 5% were pastas. Thus, the economic value of these environmental benefits provided in 2012 was estimated at $99,680, which represents the public good value that the industry generates to Florida citizens at no cost. This estimate was about 1% of the farm gate value of clam sales ($11.9 million) in that year.

Results demonstrate the important contribution of hard clam culture to coastal ecosystem services. Findings on clam farm sustainability can benefit growers, wholesalers, and retailers by allowing them to inform buyers and consumers that shellfish aquaculture is a “green” industry and, in fact, provides ecosystem services. Consumers will benefit by being made aware of the environmental benefits of sustainable shellfish aquaculture. Estimates of nutrient reduction and carbon storage may, in the future, be adopted as usable or saleable nitrogen and carbon credits, further benefiting clam growers.

Figure 4. Harvesting hard clams from an aquaculture farm located in Florida coastal waters.

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