Estimating the Value of Ecosystem Services Generated by the Hard Clam Industry in Florida

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Overview

Shellfish production not only offers market benefits to producers and consumers but also non-commercial (or non-market) benefits to society, such as “ecosystem services” (ES). For hard clam production in particular, the two primary ES are generated from denitrification, phytoplankton removal and the potential to prevent or mitigate algal blooms (Askvig et al. 2011; Cerato et al. 2004; Doering et al. 1986). These biological processes sequester carbon during shell growth and improve water quality from filtration. While these biological processes and associated ES are relatively well understood, they have yet to be valued economically as evidenced by a lack of scientific literature specific to hard clams. In order to estimate the value of ecosystem services generated from hard clam production, this study summarizes the existing literature that quantifies the ecosystem services generated by shellfish in general, the associated economic value, and the economic value of carbon storage and nitrogen removal from alternative sources of ES (i.e., rotational timber and water treatment) for comparison. These results are then used to derive estimates of net carbon and nitrogen removal associated with hard clam production in the major producing area of Florida (i.e., Cedar Key).

Ecosystem Services from Shellfish

Hard clams belong to the shellfish family and shellfish share similar biological functions. As such, the ES generated by all species of shellfish are similar. Table 1 contains a summary of available studies of ecosystem services associated with shellfish that includes the species, ES, unit of analysis, and the measurement of the ES generated. With respect to species, several studies are of clams in general, but studies of oysters and mussels are also included. The key ES are improved water quality and carbon sequestration. The unit of analysis is important since shellfish provide ES whether they are *in situ* or are cultured. The main distinction for quantifying the associated ES is whether they are measured from populations in the wild or from a farm.

Overall, clams have been found to effectively enhance water quality by preventing algae blooms and eutrophication, removing excess nitrogen, preserving water clarity, and reducing water turbidity (Higgins et al. 2011; Ferreira et al. 2009; Cerato et al. 2004; Doering et al. 1986). However, one study found a reduced benefit when considering nutrient regeneration from mussel farming in addition to the more commonly studied nutrient filtration (Stadmark and Conley 2011). However, there was still a net reduction in nutrients. Bartoli et al. (2001) find that nutrient regeneration from clam farming in Sacca di Goro, Italy may lead to a net increase in nutrients. However, they are comparing their nutrient measures with another author's unpublished measures for a region without clam farming. Variations in methods and local conditions could be driving results. Overall, most literature finds that shellfish effectively reduce nutrient concentrations.

With respect to carbon fixation, some studies argued that clams provide a carbon sink (Fry 2012; Tang et al. 2011; Baker 2011; Felbeck 1983) but when considering carbon released during respiration, clams may release more carbon from their shell and respiration than what they store in their shell (Mistri and Munari 2012; Chauvaud et al. 2003). The literature regarding the relationship between shellfish and the ability to sequester carbon is in inconclusive.

Valuation of Shellfish Ecosystem Services

The ecosystem-service valuation literature on shellfish focuses mainly on quantifying the prevention of eutrophication in waters with oysters and mussels, despite the other ES provided by shellfish, such as carbon sequestration. Most of the literature reports the estimated marginal cost of providing services such nitrogen (N) removal or phosphorus (P) removal; *marginal cost* is defined as the cost incurred to provide one more unit of the service, given what is already being provided. This metric is important because some base level of the service will always be provided in some manner; as such, the goal is to determine the cost of increasing the provision of the service from the base level.

Most studies rely on the replacement cost method to value the ES provided by shellfish. The ES provided by shellfish– most notably reduction in nitrogen levels –could be replaced by human methods such as wastewater treatment plants and agricultural best management practices or BMPs (e.g., fertilizer reduction, livestock unit reduction, conservation tillage and grassed waterways). Consequently, the ES provided by shellfish can be calculated by determining the marginal cost of replacing one unit of ES provided by shellfish with one unit of the same service provided by alternative methods. Ideally, the valuation would be based on the alternative method with the lowest cost because that would be the next best way to provide the service (from an efficiency perspective).

Nitrogen Removal Costs

Table 2 summarizes studies that were conducted in the U.S. and Europe (mainly in the Chesapeake Bay and Baltic Sea, respectively). Among all the alternatives reported for providing nitrogen (N) removal, we find values ranging from 0.11 USD kg^{-1} to 28.23 USD kg^{-1}. While the shellfish valuation literature relies heavily on wastewater treatment plant costs to determine replacement costs, Table 2 also includes abatement measures implemented for agricultural nitrogen runoff. These methods, when viable options for a given region, can be less costly than wastewater treatment.

Some of the values reported in Table 2 depend on the environmental conditions in which they were measured, implying that applying them to different conditions may lead to biased estimates of value. In particular, water turbidity, carrying capacity, and phytoplankton levels affect nitrogen removal and these factors varied across studies or were not controlled for in all studies (Grabowski et al. 2012; Gren et al. 2009; Newell et al. 2005).

Carbon Storage Costs

Table 3 summarizes information related to carbon storage (i.e., sequestration) including the amount of carbon storage and associated costs from studies that considered obtaining the ES from an alternative, such as timber production, energy production, maintenance of cropland, etc. The estimates summarized here are at the U.S. county or state level. In summary, the creation and maintenance of tree plantations is the most prevalent alternative used in the literature to value carbon sequestration. Using this alternative, costs include tree production, as well as the value of the land in an alternative use (i.e., the *opportunity cost* of the land); in areas with high agricultural, commercial, or urban land values, this opportunity cost of utilizing the land as a tree plantation is high. For example, Nielsen et al. (2014) constructed county-level measures in the

United States of the cost of aforestation considering land that is currently used as cropland, pasture, or rangeland. The cost includes the opportunity cost of producing timber instead of the current land use as well as the forest establishment and maintenance costs.

Stavins (1998) presents a summary of marginal cost (described above) and average cost (the cost of the entire provision of the service divided by all units provided) estimates of carbon sequestration from previous studies. The findings range from $0.03 to $581/t of carbon (C). On average, the estimated cost (including both marginal and average costs) is $130/t of carbon. For carbon offset prices, the literature has used a range between $0 to $300/t of carbon, and the total amount of carbon sequestrated under these costs and prices ranges from 158,000 to 700 million tons of C; the average is 103.1 million tons of C. Assumptions that affected the estimated value of carbon sequestration included the type of timberland ownership (private or public), the time horizon considered, the tree species considered for timber studies, and the interest rate used.

ES Valuation of Florida Clam Production

Using results from previous ES valuation studies, we sought to estimate the value of ES provided from the culture of hard clams in Florida. Due to the sensitivity of valuation to local conditions, we chose to utilize estimates from Burke (2009), which valued the nitrogen removal services using the costs of two wastewater treatment plants that were recently constructed in cities nearby the primary production region in Florida (i.e., the plants were in Clearwater and Fort Meyers, and the vast majority of culture production occurs in Cedar Key). Replacing the same nitrogen removal services provided by Cedar Key clams would require treating water near Cedar Key, so the estimate from Clearwater ($3.44 per pound of nitrogen removed) is the best approximation. For clam-producing regions closer to Fort Meyers or in areas with higher land values and cost of living, the estimated value is $5.22 per pound of nitrogen.

The cost per metric ton of carbon sequestered was calculated for all clam-producing counties in Florida using reported estimates of land values by alternative uses and county (Nielson et al. 2014). The cost included a weighted average of the opportunity 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 to lower land values in the more rural county.

Summary

Shellfish grown in situ or as part of a cultured system generate ecosystem services that have economic value above their commercial value as a food source. The process of deriving estimates of the value of ecosystem services is well-documented and studies have consistently shown that both the quantities of ecosystem services that are generated and the valuation of those services is dependent on a myriad of factors; however, these values are critically important to policy makers that are charged with decisions involving potential public investments designed to improve environmental quality (both of the water and the air) that can also be obtained from protecting or expanding shellfish culture (and at potentially lower cost to the public). This study sought to estimate the values associated with the hard calm industry in Florida, where product prices have recently fallen; low product prices can result in lower production levels with adverse effects on environmental quality (i.e., higher levels of N and P, and more C in the atmosphere).

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Table 1: Summary of Ecosystem Services Estimated from Shellfish Production

Authors	Species and Study Area	Sample	Measure of the service
Baker, 2011	Hard clams (*mercenaria mercenaria*) in Cedar Key, FL	1 bag (921) clams > 5mm, 76.2% harvested clam, 14.7% dead, 8.4% oyster	CO_2 seq. mean rate: 2.9 g/clam (Florida industry: 534 MT in 2008)
Bartoli et al. 2001	Short-necked or Manila clams (*Tapes philippinarum*) in Sacca di Goro, Italy	480 to 2336 clams of commercial size m^{-2}	Oxygen consumption mean rate (mmol O_2 m^{-2} ha^{-1}): –12.49 (±4.54) with clams and –2.67 (±0.58) no clams; CO_2 production mean rate (mmol O_2 m^{-2} ha^{-1}): 10.42 (±5.61) with clams and 1.22 (±0.81) no clams.
Cerrato et al. 2004	Hard clams in the Northern shore, Peconic Bays Estuary System, Southold, NY	Seawater samples without clams and with clams of varying densities	Water clearance mean rate (l $clam^{-1}$ ha^{-1}): 0.07 to 1.2 (± 0.4)
Chauvaud et al. 2003	Asian clams (*Potamocorbula amurensis*) in Northern San Francisco Bay, CA	Monthly collection from densities of 2 - 16,000 m^{-2}, Jun 1988 – Nov 1994	Net CO_2 release mean rate (g C m^{-2} yr^{-1}): 55 (± 51) CO2 release mean rate: 18 (± 17) from shells (or calcium carbonate) and 37 (± 34) from respiration
Doering et al. 1986	Hard clams in Narragansett Bay, RI	4 mesocosms with clams (16 clams m^{-2} of 3.2-10.7 cm, half avg 6.71 ± 1.89 cm and other half avg 6.73 ± 1.87 cm) and without clams	N removal (consumed) rate: 30% - 46% of the excess biomass produced a day
Felbeck 1983	Gutless clams (*Solemya reidi*) in Santa Monica Bay, Los Angeles, CA	Wild clams from 1-3 g collected at depth from 100 - 120 m	CO_2 seq. rate (umol/g fresh weight): 5.0 (±2.4) for *Solomya reidi*;

Authors	Species and Study Area	Sample	Measure of the service
Ferreira et al. 2009	Pacific oysters (*Crassostrea gigas*), blue mussels (*Mytilus edulis*), Manila clams, mussels (*Mytilus gallo- provincialis*) in Portugal, France, Slovenia, Italy and Scotland	Collection from 5 different systems: Loch Creran, Pertuis Breton (macrotidal bay), The Bay of Piran (shallow basin), Chioggia (Adriatic coast), The Ria Formosa (hypersaline barrier island lagoon system)	Net N removal (tons N yr^{-1}): 0.7 in phytoplankton and 8.1 in detritus, or 1206 population equivalents (PEQ) per year, by oyster culture (Loch Creran); 309 and 323, or over 200,000 PEQ by blue and Mediterranean mussels (Pertuis Breton and Chioggia); 28.5 by clams (Ria Formosa).
Fry 2012	Mussels and Pacific oysters in Scotland	2010 data from 3 mussel and 2 oyster farms representing 23% of mussel and 37% of oyster production in Scotland	Carbon seq. rate: 218 kg CO_2 per ton of mussels harvested and 441 kg CO_2 oysters harvested, from harvested shell and dead on thinning/grading
Higgins et al. 2011	Eastern oysters in Chesapeake Bay	Oyster tissues and shell	Removal rate (kg): 132 total nitrogen (TN), 19 total phosphorous (TP), and 3823 total carbon (TC) for 10^6 harvest-sized oysters; 378 TN ha^{-1}, 54 TP ha^{-1}, and 10,934 TC ha^{-1} for 286 oysters m^{-2}
Mistri and Munari 2012	*Ruditapes philippinarum* in the Lagoon of the Po Delta River, Italy	20 clam farms were sampled monthly for a year, total 401,545 kg (1148.6 g m^{-2})	CO_2 seq. mean rate (molCO_2 m^{-2} yr^{-1}): 8.18 from shells and 5.56 from calcification Gross CO_2 release mean rate (molCO_2 m^{-2} yr^{-1}): 22.7 from respiration
Reitsma and Murphy, n.d.	Hard clams in coastal MA	24 harvested and 24 wild clams of 1-1.5 inch shell thickness	N removal rate (assuming 2,500,000 harvested littlenecks): 500 kg of N
Rice, 2001	Northern quahogs in the Providence River section of Narragansett Bay	9.1 clams m^{-2} (about 26,400 MT)	Filtering rate: approximately 1.0 x 107 m^3 d^{-1} of water
Riisgard and Seerup 2003	Soft clams (*Mya arenaria*) in Pughavn at Fyns Hoved, Funen, Denmark	Sample collected in October 2000 and August 2001, five clams of 27.8±1.5 mm	Filtering rate: nutrients and total suspended solids up to 0.18 m^3 $clam^{-1}$ d^{-1} of water.

Authors	Species and Study Area	Sample	Measure of the service
Stadmark and Conley 2011	Blue mussels in Baltic Proper	Estimated sample: 40–90 tons ha^{-1} yr^{-1}	Total potential reduction: 320–720 ton of N and 19–43 ton of P per year with that density
Tang et al. 2011	Chinese scallop (*Chlamys farreri*), Blue mussel, Pacific oyster, Manila clam *Tapes philippinarum*, Ark shell (*Scapharca subcrenata*), Clam (*Mactra chinensis*), and seaweed in China	From 1999 to 2008, through the activity of shellfish and seaweed mariculture (shell and tissue) and seaweed	Total CO_2 production mean rate: 3.79 ± 0.37 Mt C yr^{-1} (total 37.89 Mt C, over the period) production. Total CO_2 removal mean rate: 1.20 ± 0.11 Mt C yr^{-1} (total 12.04 Mt C) by harvesting. Individual CO_2 removal mean rate: 0.86 ± 0.086 Mt C yr^{-1} by shellfish and 0.34 ± 0.029 Mt C yr^{-1} by seaweeds.

Note: Several species names including *Ruditapes philippinarum*, *Tapes philippinarum*, and *Venerupis philippinarum* are included in the literature and all refer to the same clam species.

Table 2: Summary of Literature that Values Reduced Nitrogen (ES from shellfish) by Different Methods

Authors	Species and Study Area	Measure of the service	Cost and Method
Burke 2009	Manila clams (*kumamoto*), Pacific oysters and mussels in Oakland Bay	25,787 pounds of N per year (Steinberg and Hampden, 2009)	$6.93/kg in Clearwater, FL and $2.16 - $9.39 for other locations from wastewater treatment plans assuming capital cost annualized with 6% discount rate over 20 years
Chyzheuskaya et al. 2012	Ireland	Agricultural measures including: fertilizer reduction; livestock unit reduction; change in feed mix; higher yielding dairy cows; more efficient slurry application	$0.82 - $10.87 for N removal from ag BMPs
Grabowski et al. 2012	Oyster reefs in Chesapeake Bay	Net N removal rate (micromoles m^{-2} h^{-1} dr^{-1}): 246 (oyster reef) and 12 (Soft-sediment bottom) ; SAV: 1 ha of oyster reef would create 0.005 ha of SAV	$28.23/kg assuming N removal price equals the current mean trading price in the NC Nutrient Offset Credit Program set by North Coast Atlantic Conference Rule no. 15A NCAC 02B .0240
Gren 2008	Baltic Sea	Reductions in N from changes to agricultural practices, wastewater treatment plants, reducing air emissions, and constructing wetlands	Lowest cost: $1.06 - $2.59/kg for N removal

Authors	Species and Study Area	Measure of the service	Cost and Method
Lindahl et al. 2005	Blue mussel (*M. edulis*) in Eastern Skagerrak, Sweden	28 tons of nitrogen removal by production of 2800 t of mussels (500 mussels per meter suspender) per year	\$9.70 - \$14.4 from wastewater treatment plant
Newell et al. 2005	Eastern oysters (*Crassostrea virginica*) in Choptank River, Chesapeake Bay, MD	oyster stocks of 1 m^{-2} burying and denitrifying 13,080 kg N annually	\$4.60 - \$1,250/kg N (average of \$24.07) based on MC of N abatement from the EPA Chesapeake Bay Program
Pollack et al. 2013	Oysters (*Crassostrea virginica*) in Mission-Aransas Estuary, TX	N removal rate (kg km^{-2} yr^{-1}): 502.5 denitrification of biodeposits and 251.3 in burial of biodeposits to sediments (oyster reef); 21,665 r via physical transport from the system (harvested)	\$8.50/kg from costs of water treatment (quantity of N removed by oysters as % of total N removed by treatment plant; that % of costs used to calculate value)
Rabotyagov et al. 2010	N/A	Conservation tillage (mulch, ridge, and no till); contour farming; grassed waterways, terraces, and all crop production replaced with perennial cover.	\$0.26 - \$0.70/kg for N removal from ag BMPs
Wustenberghs et al. 2008	Flanders, Belgium	Various agricultural measures including: increase dairy production efficiency, decrease fertilizer, and increase buffer strips, conservation tillage, winter cover crops and water recycling	\$0.11 - \$1.56.kg N for reduction in surface water pollution from ag BMPs and improved land management

Table 3: Findings of Carbon Storage Costs

Authors	Species and Study Area	Measure of the service/Methods	Cost
Balderas et al. 2009	Chiapas, Mexico	Cost to adopt practices that sequester carbon including tropical afforestation, living fences, and tropical fallow	\$11.17 to \$22.08/t C
Callaway and McCarl, 1996	major agricultural production regions in the U.S.	Agricultural Sector Model used to determine carbon sequestration costs under different agricultural subsidy programs	\$15.76 to 51.30 per 10^6 short ton/year
Guitart and Rodriguez 2010	Eucalyptus in Bahia, Brazil	Carbon payment necessary to induce additional sequestration of carbon through lengthened rotations	\$6.52 to \$7.39 /t of CO_2 per year
Moulton and Richards (1990)	10 farm production regions in the U.S.	Cost of sequestering carbon in forests, assuming that most appropriate species and timber practices used in each region	\$5 to \$43.33/t C
Nielsen et al. 2014	County-level estimates for the entire U.S.	Opportunity cost of conversion of agricultural land to timber plantation plus timber planting and maintenance costs, with and without timber harvest revenue	\$18.43/MT with timber harvest, \$58.1/MT without timber harvest
Parks and Hardie, 1995	U.S.	Simulation model used to determine cost of converting agricultural land to forests, assuming that the landowner optimally allocates land to timber and agriculture	\$76.13 to 220.24/t C
Plantinga et al. 1999	Local species (not explicitly stated) in Maine, South Carolina, Wisconsin	Cost of afforestation projects determined through simulations calibrated by econometric estimation of land use shares as a function of socioeconomic and demographic factors	\$45 - \$120/t of C
Stavins 1998	Mixed stands and pine plantation (loblolly and pine) in Arkansas, Louisiana, Mississippi	Cost of afforestation projects, assuming that the landownder optimally allocates agricultural land to forest	\$8/t (Delta states), \$70/t U.S.
Strengers et al. 2008	Global	Use of Integrated Model to Assess Global Environment (IMAGE) to construct carbon abatement supply curves	Average of \$138/t C at baseline values