The State Is Your Oyster:

Cultivating Oyster Farming in North Carolina

by

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Executive Summary

Oyster mariculture represents economic and environmental opportunities across a wide array of stakeholders in North Carolina. The objectives of this project were to build a business case detailing the advantages and disadvantages that new smallholder oyster farmers might face as they enter the industry, and to make recommendations that would improve market access and business management options for those new oyster farmers. Scrutiny of the existing local oyster industry landscape, regulations and legislative proposals, and the environmental impacts of oyster farming revealed areas where the business case for oyster mariculture in North Carolina could be strengthened and the incentives throughout the industry better aligned.

Our team investigated the current state of the industry by examining primary and secondary resources and conducting our own semi-structured interviews with relevant stakeholders. To understand the various forces shaping the oyster industry, the team used an analytical tool called PESTEL. The PESTEL framework is traditionally used to evaluate new business ventures, and its letters stand for Political, Economic, Social, Technological, Environmental, and Legal dimensions of a given industry. A review of Life Cycle Analyses (LCA) was performed in order to evaluate and prioritize recommendations in terms of their environmental effects. Interviews with oyster farmers, hatchery employees, state regulators, economists, and Extension agents were administered in order to better understand the perspectives and interests of critical industry participants.

The three components of our analysis were PESTEL, a toolkit for farmers, and LCA.

- The PESTEL analysis assessed established practices and found room for improvement within each of the six categories. Major themes included: location siting, permitting, and NIMBY attitudes; how to balance North Carolina’s cultural embrace of small businesses with sufficient support for the unique needs of smallholder farmers; availability of appropriate technology; and the role of regulatory agencies.
- The tools summary and analysis compiled existing tools and resources for oyster farmers, gave recommendations on how best to utilize them, and identified ways to fill any existing gaps in coverage. The primary applications for these tools were in siting the parcel of an oyster farm; initial and ongoing financial modeling for the business; and processes of actually raising and purveying oysters, including growing, tracking, cleaning, packaging, marketing, and selling them.
- The LCA Analysis examined the three stages of the oyster life cycle. The birth-to-harvest analysis showed the need for commercial seed hatcheries, central locations for those facilities, and the reduction of fuel and other non-renewable material inputs. The transportation analysis evinced the environmentally optimal types of short and long transportation supply chains, including direct deliveries to retail, on-farm sales to intermediaries, and sales to the wholesale market. The end-of-life analysis demonstrated the exigency of state-wide shell recycling programs, and shorter transportation chains to the requisite processing plants.

The results from PESTEL, the toolkit, and the LCAs yielded recommendations directed at North Carolina state agencies, legislators, non-governmental organizations (NGOs), and oyster farmers.

- State agencies: Accelerate the rollout of the Shellfish Enterprize Area/Zone (SEA/SEZ) pilot program to achieve faster permitting, perform community education to reduce NIMBY resistance, and use existing data to better tailor finance and skill training resources to industry participants.
- Legislators: Evaluate the utility of bundling low-interest financing and business plan support, consider the creation of a financial incentive program for farmers based on oyster environmental benefits, fund seed hatcheries and recycling facilities, and contemplate changing the industry regulator from the Department of Marine Fisheries (DMF) to the NC Department of Agriculture (NCDA) to better support and liaise with oyster farmers.
- NGOs: Create programs to foster collaboration among new industry entrants, so as to increase market access through shared resources and additional technology-enabled revenue streams.
- Farmers: Take advantage of the existing tools and resources to build more robust and resilient farm businesses, anticipate at least one year's time from siting/permitting to starting operations, and plan for up to the first three years in business without making a profit.

In conjunction with our results and recommendations, there were several areas we identified for further research.

- First, the State should evaluate locations for seed hatcheries and recycling facilities that would be able to optimally support the growing industry while minimizing negative environmental externalities.
- Next, the LCAs that were analyzed in this report should be constructed or calculated using local transportation and farming materials data.
- Additionally, the State should evaluate the viability of a payments for ecosystems services (PES) model by funding primary research into the oyster's water nutrient reduction and carbon sequestration potential.
- Finally, the State should examine the feasibility of switching regulatory oversight of oysters from the DMF to the NCDA.

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Introduction

The U.S. aquaculture industry makes an estimated $1.5 billion in revenue annually (National Oceanic and Atmospheric Administration 2021) and faces growing domestic demand each year (Naylor et al. 2021). Oysters are one of the top U.S. marine aquaculture species and represent almost 20 percent of this total (National Oceanic and Atmospheric Administration 2021). The state of North Carolina has an oyster aquaculture industry that produced $2 million worth of farmed oysters in 2018 and has the potential to become the "Napa Valley of oysters" (Mosher 2018). Additionally, coalitions of stakeholders have been working for over two decades to protect and restore N.C.'s oyster habitats and fisheries. Proposed aquaculture regulation and action blueprints have been published to provide guidance and direction to existing stakeholders (North Carolina Coastal Federation 2020). The growth in the oyster aquaculture industry in North Carolina has followed on the heels of similar growth in neighboring states, such as Maryland and Virginia. Oyster farmers from those places have come down to North Carolina to do shellfish production, because there is plenty of freshwater access near the coast and lots of space in the waterways and estuaries (NC Department of Agriculture 2022).

As North Carolina seeks to catch up with neighboring states and build a robust state oyster economy, viable pathways to prosperity must be accessible across the entire value chain. A value chain is "a business model that describes the full range of activities needed to create a product or service" (Tardi and Brock 2020), which for oysters includes farming, marketing, and distribution. For new growers, acquiring area for cultivation is a major hurdle, with the North Carolina coast crowded by stakeholders who claim the space for many disparate purposes (Smith 2021); under these conditions, it is more complicated and less likely for larger aquaculture parcels to be established. In oyster farming as in any business, the local context and the entrepreneur's goals are major factors in a firm's possible profitability, but financially successful NC shellfish mariculture exists over a wide range of scales (NC Department of Agriculture 2022)–and in farming, parcel size has implications for both the farmer and their surrounding community

(Poole 1981). Within the business, total area in cultivation directly influences not only profit potential, but also necessary inputs of labor and materials, and types of contracts available. Building the business model begins with the question of how many people will be supported by a given enterprise (Aquaculture Economist 2022). Outside the firm, the array of producers in the market shapes the culinary options for consumers as well as the community life in the areas around farms. Local food culture benefits when smallholder growers sell directly to consumers through farmers' markets or Community-Supported Fishery (CSF) programs, or supply fresh ingredients to chefs and restaurants in the area (Schnell 2007, Feagan and Morris 2009, Inwood et al. 2009). Civic engagement improves when area businesses are owned and operated by local citizens and taxpayers (Clark and Record 2017).

Background

North Carolina's encouraging top-line revenue growth in oyster production encompasses the contributions of firms throughout the value chain, especially farms. The size of a farm is key in influencing whether a given enterprise can achieve economies of scale and bring profitability within reach, whether that farm is terrestrial or aquatic. In American land agriculture, there has long been a distinction drawn between farming for a living and farming for profit (Dixon and Hapke 2003), with many growers traditionally making enough to cover expenses but not to pay themselves a salary or otherwise have any money left over. There are several measures of the "efficiency" of a farming enterprise: scale, or whether an entity is operating at its most productive size (IGI Global); technical, or whether an entity is maximizing output given specific inputs and context; and economic, or whether an entity is selecting inputs to maximize profits, given market conditions (Paris 2016). A critical factor to include in analyses of farm efficiency is farm size, which can be defined by acreage but is more often categorized by revenue (or "farm income") (Vitale et al. 2019). Of course, the intuitive groupings of farms by revenue depend somewhat on geography and what is being cultivated, but in one study of wheat farms in the Great Plains, farmers making "annual crop revenue in excess of $500,000 were classified as large; those with revenue between $250,000 and $500,000, as medium; those with revenue between $100,000 and $250,000, as small; and those with revenue less than $100,000, as very small" (Vitale et al. 2019). That study found that small farms were scale-efficient and large farms were technically and economically efficient (Vitale et al. 2019), a result echoed in many other papers (e.g. Tveteras and Battese 2006). In other words, small farms were operating at their most productive sizes, while large farms chose inputs that maximized both their profits and outputs given market conditions and context. Other papers dispute the scale efficiency claim; one such paper finds "family farms" to be "both scale and technically inefficient" (Paul et al. 2004), which introduces the need to distinguish between "small"/"smallholder" and "family" farms.

The definitions of the terms "small farm" and "family farm" have evolved over time and sometimes overlapped. While "small farm" refers mostly just to the size of the business or the acreage, "family farm" embodies not only the scale (of the parcel, business, and/or family group), but also the ownership model (of tenancy or possession), the management power (by a family unit), and the land security (whether farming is the central income, second income, or declining and phasing-out income for the household) (Effland 2021). Since the farm financial crisis in the '80s saw a wave of large, corporate, family-owned farms suffer bankruptcy and foreclosure despite generous subsidies and technical assistance from the federal government, many people have since tried to nest an implication of "small" within the idea of "family farms" (Effland 2021). That trend has intensified in the twenty-first century, with growers and consumers alike advancing a "broader critique of the food system" that opposes large-scale, corporate agribusiness and detachment from the land, and embraces "food safety, nutrition, and environmental concerns" (Effland 2021). Farm size matters too in its impact on the social fabric of communities nearby farms: "the smaller-scale farm economy tends to promote a higher quality of life in rural communities," while "the large scale farm economy leads to the deterioration of rural community life, including the stagnation of social organizations, the constriction of public services, and the erosion of local community control" (Poole 1981). To narrow and clarify the scope of inquiry, this analysis is concerned with “smallholder” farms–defined by Vitale et al. as $250,000 or less in annual revenue–but the intersection of “small” farms and “family” farms is valuable to note.

With optimal technical and economic efficiency generally out of reach for small farms, scale efficiency–that is, choosing the most productive size for the farm–becomes all the more vital. The more mechanized and commoditized farm outputs become, the less control farmers have over their economics (Sehmsdorf 2021), so the diversity of practices small farmers utilize is especially valuable in that it allows for the tweaking of growing tactics to achieve better efficiency. One study showcasing the value of creative approaches examined the economics of US catfish production strategies, finding that “different types of management models can achieve similar levels of production costs…and it appears that there is not one single economically optimum way to raise catfish” (Johnson et al. 2014). Given its lesser size and more limited balance sheet, a small farm faces higher risk exposure than a medium-scale counterpart, but “while the risks of not reaching viability in microfarms are not to be neglected” (Morel et al. 2017), a prudently managed small farm can reach solid financial solvency. In the case of oysters, the value of fresh, local specimens to replace more distantly sourced imports has been confirmed in Hawai’i, where since 2014, chefs have been paying a premium for the first opportunity in decades to buy locally grown oysters (Chen et al. 2017). In addition to direct marketing tactics, value-added processing is another of the “commonly recommended strategies for increasing income and improving the economic viability of small farms” (Clark 2020), along with the Community-Supported Agriculture (CSA) model (Galt et al. 2012), in which community members pay once for a whole season of weekly farm produce harvest boxes.

Market Players

Shellfish mariculture in North Carolina is an important endeavor to many stakeholders. Producers gain their livelihoods from it, restaurants rely on its supply for their menus, consumers all along the Eastern seaboard enjoy its bounty, policymakers recognize the state economy as stronger for its contribution. The environments along the coast gain resilience from its many associated ecosystem services, like oysters filtering sediment and nitrogen out of the water, recycled shells providing habitat for future oyster populations, and living shorelines protecting the land and its inhabitants from storm surges and erosion. In recognition of the enormous advantages obtained by promoting shellfish mariculture, a wide and diverse group of stakeholders has coalesced to push the industry forward in the state.

The business models and practices employed by individual shellfish mariculturists matter to all of the above stakeholders because they involve prioritizing different goals. Growers pay attention to the bottom line, so they might look for ways to conduct their work more cheaply (MD Sea Grant 2022). Restaurants need steady inventory, so they might prefer larger contracts with fewer producers (Oyster Farmer 1 2022). Consumers seek variety as well as local fare, so they expect the supply chain to facilitate both outcomes (Sea Level NC 2022). Policymakers want the state's economy to grow, so they aim to promote the industry and keep the largest percentage possible of the profits here in North Carolina (Fodrie et al. 2018). And if the shoreline could talk, it might advocate not only for elevated oyster production to capture more of those valuable ecosystem services, but also the selection of local seed and oyster species and other thoughtful tactics to maximize coastal resilience (Smith 2021).

No matter whom you ask, they might all agree that the process of growing oysters in North Carolina starts with the producers themselves, who raise the creatures from seed to adult and sell them to parties who then prepare them as delicious fare. Shellfish mariculturists have many judgment calls to make, the first of which being whether to enter the industry at all. Once someone decides to grow oysters, subsequent determinations include selecting a location, making choices of gear and seed, setting strategies for marking and patrolling the parcel, adopting protocols for addressing disease among the farmed creatures, finding markets for the adult specimens, and more. This inquiry centers on one such decision oyster growers must make: what size of a parcel to lease and farm.

The objective of this project is to make a business case that analyzes the advantages and disadvantages that new smallholder oyster farmers may face as they enter the industry and makes recommendations that will improve the industry for them. The project will use this business case lens to examine the current role of stakeholders in policy-making, economic dynamics, societal trends and consumer demand, technological potential, environmental impacts, and legal ramifications that new oyster farmers will face as they enter the industry, and identify and plan around challenges that those new entrants may face. We will be using the PESTEL framework to structure the business case and to get a well-rounded understanding of these factors that are at play. Additionally, we will incorporate three life cycle analyses that align to three general phases of oyster production and consumption in order to make specific recommendations that will optimize environmental impacts as the industry grows. Oyster mariculture in North Carolina is a relatively new industry that has been expanding rapidly and has further potential for growth. In order to continue to drive new participation in the industry, our recommendations will consider the interests of the various market players who all contribute towards a successful business case for oyster mariculture in North Carolina.

Objectives

After doing an initial literature review to develop an understanding of the history, current status, potential, and major stakeholders in the oyster mariculture industry in North Carolina, we distilled the following objectives to structure our project. In addition to addressing some areas that we perceived as most relevant to the industry overall, the objectives also reflect team members' areas of expertise and interest.

Objectives:

1. Develop a multi-dimensional business case for smallholder oyster mariculture in North Carolina.
2. Analyze existing legislative proposals intended to facilitate market entry by new smallholder oyster farmers.
3. Assess existing life cycle analysis (LCAs) of oysters: birth to harvest, transportation, and recycling of shells. Apply insights to recommendations specific to North Carolina.

Materials and Methods

Interviews

As the North Carolina oyster market is complex, dynamic, and fast-growing, it is useful to supplement insights from the literature review with granular qualitative data from current players in the industry within North Carolina. Personal conversations permit nuanced exploration of the topics at hand as well as the development of interpersonal rapport, both elements which build trust and yield valuable information. In order to gather firsthand commentary from industry participants, we conducted 15 interviews via Zoom video conference in January and February 2022. Targeting participants involved using the Internet to build lists of potential interviewees across a wide array of stakeholders, including oyster farmers, hatchery employees, state regulators, economists, and Extension agents. The final sample of interviewees is a combination of those who responded to interview requests and those who were recommended via snowball sampling with our initial contacts. This research project and interview protocol went through the IRB process to ensure the procedures minimized risks to the participants. An interview guide with pre-written questions spanning several topics–including regulations, seed sourcing, permitting, and more–was used to guide the semi-structured interviews and categorize responses into themes (see Appendix A). Team members manually typed notes during the interviews, and the interviews were recorded to allow team members to return to the dialogue afterwards while reviewing their notes, to fill in any gaps or correct any errors. Each transcript was coded by the person who scheduled the interview and reviewed by the other team members, and then the whole team discussed, clarified, and reconciled any ambiguous, confusing, or conflicting classifications to produce a clean body of evidence to parse. Final recommendations at the end of this paper stem primarily from insights provided by interviewees.

PESTEL

PESTEL is a business analytical framework that can be used to better understand the external forces that are affecting an organization or business before making a decision to launch a new project or business venture (Pestel Analysis 2022). The letters in PESTEL stand for Political, Economic, Social, Technological, Environmental, and Legal, and each letter represents an aspect that needs to be researched and analyzed before reaching a final decision on a project or business venture. This framework can be applied in a variety of situations and is useful both for established businesses that are looking to expand to additional markets and for new businesses that are planning to enter the industry. While the true history of this analytical framework is hard to establish, the earliest known reference is commonly cited as Francis J. Aguilar's book Scanning the Business Environment in 1967. Aguilar first introduced "ETPS," referencing the economic, technical, political, and social aspects of his analysis (Reding 2021). The analysis quickly grew to include more areas of focus and evolved to various mnemonics, one of which is PESTEL (Reding 2021).

Examining the oyster farming industry through each aspect of PESTEL can help new entrants into the industry as well as existing stakeholders, such as government officials and existing oyster farmers, to make strategic business decisions. In the context of this project, the PESTEL framework will be used to build a business case for small-scale oyster farming within North Carolina.

Life Cycle Analysis (LCA)

A life cycle analysis is a methodological approach used to quantify the total environmental impacts of a product, service, process and/or system (Jolliet 2016). Typically, "in a life cycle analysis or assessment, the total and comparative impacts of the life cycle stages are considered, with or without quantification of those impacts" (Matthews 2014). The total and comparative impacts are calculated based on the inputs and outputs of what is being measured within a specific boundary. Based on the results, impacts such as greenhouse gas emissions can be quantified, or alternative options can be compared based on which has the least negative or most positive impact.

Oyster farming practices vary depending on the geography, required equipment, and chosen production methods of growers. The system boundaries of an LCA of oyster aquaculture can include farmed birthing methods (single-seed or clutched oysters), production methods (hatcheries, nurseries, and grow-outs), and processing methods (Pucylowski 2017). LCA scope can be defined as broadly as the inputs and outputs from all previously mentioned systems, or as narrowly as the comparison of environmental impacts from importing seeds from out of country or state compared to local seed supply chain (Tamburini et al. 2019). Additionally, LCAs have been conducted to compare the greenhouse gas emissions of oyster farming with those of terrestrial livestock production (Ray et al. 2019). Research has also been performed on the methodologies used to conduct aquaculture LCAs, providing recommendations for improving the quality of future aquaculture LCAs (Henriksson et al. 2012).

Transportation is an integral part of oyster LCA. Oysters must be transported from farms to processing facilities to seafood distributors, markets, and restaurants (Pucylowski 2017). Transportation methods require the LCA inputs of vehicle fuel and some type of refrigeration during transport and storage. LCAs specific to oyster refrigeration may not currently exist, but the comparison of different chilling methods of fish species has been performed (Claussen et al. 2011). A published review of 59 LCAs has compared various transportation methodologies along different stages, including farm to processing plant, processing plant to port, processing plant to wholesaler, processing plant to retailer, and retailer to household (Ruiz-Salmon et al. 2021).

Oyster shells have a variety of end-of-life uses that can change the LCA of an oyster when compared to sending the shells to the landfill. Existing LCAs have found that there are significant environmental benefits of landfill avoidance of shells in favor of calcium carbonate production, provided the processing facility is within 323 kilometers from the shell collection sites (Freitas de Alvarez et al. 2012). Although LCAs for more specific end-of-life use cases for oyster shells may not exist, we may be able to utilize existing research on these use cases to inform our own LCA. Examples include using oyster shells in reef restoration (Howie et al. 2021), as treatment filler for wastewater in estuaries (Lou et al. 2013), for use in fireproofing material (Peceno et al. 2021), and as drainage material to increase soil suitability for cultivation or construction (Jeon et al. 2020).

A life cycle analysis will reveal the benefits and negative environmental externalities of oyster mariculture, which we can then apply towards the PESTEL framework. With this approach, we can identify and categorize the inputs that go into the oyster value chain, and identify the outputs that are either helpful or harmful to the business case. Because of the numerous production inputs, stakeholders involved in the supply chain, and various methods of shell disposal and recycling, separate LCAs can be conducted to help identify and define impacts of these specific processes.

Results

PESTEL Analysis

PESTEL - Political

Interest in and evidence of government agency collaboration varies widely by state, moderate in NC. In North Carolina, there are many government agencies with jurisdiction over coastal environments. There are five agencies that directly affect oyster farming because they are involved in the process of vetting oyster lease applications. The Department of Marine Fisheries monitors fish habitat and recreational and commercial activities; Marine Control keeps track of user conflicts; Shellfish Sanitation and Water Resources together adjudicate the closure status of waters based on water quality and public health and safety; and Coastal Management keeps abreast of coastal development and takes note of what kind of structures an aspiring oyster lease applicant is requesting to build on their lease (NC Department of Marine Fisheries 2022). Other agencies–like the US and NC Departments of Agriculture, the Army Corps of Engineers, and the National Oceanic and Atmospheric Administration–also have roles to play in supporting farmers and protecting the environment, but they are not formally involved in the NC oyster farm permitting process, except to offer third-party expertise when requested (NC Department of Agriculture 2022). The Department of Marine Fisheries (DMF) is statutorily responsible for managing the permitting process for obtaining an oyster mariculture lease. The process is complex, and after the applicant provides DMF their desired lease coordinates and DMF checks the area for the presence of submerged aquatic vegetation (SAV) and natural shellfish beds, the third step involves DMF soliciting application review and comment from the five separate agencies listed above (NC Department of Marine Fisheries 2022). DMF performs loose coordination of these agencies, but there is no formal structure or plan for getting everyone on the same page (NC Department of Marine Fisheries 2022). In other states, the atmosphere surrounding state regulation of aquaculture permitting is different. For example, in Arkansas, the governor—regardless of party affiliation—has long recognized the economic power of aquaculture and the state's need for strong industries to generate jobs and revenue. Thus, the governor insists that agencies collaborate closely and consistently, and walk together in implementing relevant statutes (Aquaculture Economist 2022). This coordination helps speed the lease process along and avoid misunderstandings.

But even the informal incentive for oyster industry stakeholders to work together to advance the industry is by no means assumed. For instance, in Georgia, there is widespread and staunch opposition to aquaculture, which has hindered the development of the state's shellfish industry (Aquaculture Economist 2022). In every state, there are interest groups—both local and national—who make known their resistance to aquaculture (Knapp and Rubino 2016). Landowners, many wealthy, often don't want nearby farms to de-value their views (Oyster Farmer 2 2022), and they are joined by environmentalists and fishers in their dislike of aquaculture, for ecological and economic protection reasons, respectively (Knapp and Rubino 2016). In Alaska, when farm-raised salmon was just being introduced, salmon fishers put out powerful misinformation about salmon farming ruining the environment because they were concerned about aquaculturists reducing prices for wild-caught salmon (Knapp and Rubino 2016). Even after the salmon fishers realized they could still make comfortable livelihoods with farm-raised salmon, they continued their protectionist public relations campaign against aquaculture (Aquaculture Economist 2022). These myths have been picked up by fishers and environmentalists in places like Georgia, who then unite with the often comparatively richer landowners to apply pressure on the state legislature and individuals in state agencies to alter the laws and regulations being implemented (Aquaculture Economist 2022). In still other states, the dynamic is reversed: for example, in Wisconsin, state agencies actually run their own aquaculture operations–at a much higher cost–and actively compete with private producers, somewhat dampening the otherwise warm aquaculture community there (Aquaculture Economist 2022). North Carolina has a receptive political environment to aquaculture, but there are many interests represented by the involved actors, and the local environmental groups actively obstruct the industry (NC Department of Agriculture 2022).

Local and non-local interest groups active in mariculture. From Alaska to Georgia to North Carolina, these examples illustrate that it is not sufficient for oyster mariculturists to be on good terms with their neighbors: for the industry to thrive, it is necessary for farmers to be aware of the activities of these other interest groups as well. As these cases also illustrate, many of these groups are far from local: for example, in Maine, well-funded outside industry groups oppose re-circulating aquaculture and have fielded lawsuits against it—even though local groups support it (Aquaculture Economist 2022).

Efforts to reform the permitting process involve complex politics that evolve over time. As the waters in North Carolina are "public trust," that means everyone has a claim to them (NC Department of Agriculture 2022), which makes reforming the complicated permitting process even more difficult. One example of this phenomenon happened several years ago, when the Submerged Aquatic Vegetation (SAV) restriction on lease siting was extremely stringent in the eyes of the farmers. By statute, if DMF discovers that a site hosts more than 50% SAV or natural shellfish beds, the Army Corps of Engineers prevents the establishment of an aquaculture lease there (Oyster Farmer 4 2022). The administration of this restriction was quite harsh for farmers, but no one on the state level was engaging the Corps on the topic—individual growers were contacting the Corps themselves (Oyster Farmer 4 2022). Then, the North Carolina Coastal Federation—a non-profit that promotes oyster farming and other coast-rejuvenating endeavors in the state—mounted a campaign to showcase the advantages of a thriving oyster industry to state politicians, in order to motivate those elected officials to deliberate with the Corps on the topic (Oyster Farmer 4 2022). After politicians were convinced that oyster farming was good for the environment, yielded local rural jobs, strengthened the economy, and was appealing across party lines, representatives got the Corps to back off to a 15% exemption for SAV (Oyster Farmer 4 2022). In general, the crowded space around aquaculture means there are "lots of politics to work out, though everyone [in North Carolina] agrees that 'oysters are good'" (NC Department of Agriculture 2022).

Today, with a much more developed aquaculture industry in the state, the topics being discussed are increasingly nuanced and complex. New entities have arisen to dissect pending regulatory issues and educate the legislature about them, like the Shellfish Mariculture Advisory Committee (SMAC). The SMAC was born of state legislation in 2016 (S.L. 2016-94 Section 14.11.(d)) and 2018 (Senate Bill 257) that "direct[ed] the North Carolina Policy Collaboratory to convene stakeholder meetings aimed at advancing efforts to bolster North Carolina's shellfish industry" and "add[ed] a mandate for the North Carolina Policy Collaboratory to prepare a Shellfish Mariculture Plan by December 31, 2018" (Fodrie et al. 2018). The NC Policy Collaboratory then created the SMAC, whose "membership represents academia, regulatory agencies, non-governmental organizations, and industry stakeholders to develop recommendations that would promote the growth of a socially, ecologically, and economically responsible shellfish mariculture industry" (Fodrie et al. 2018).

The SMAC recently delivered 18 substantive suggestions to the NC state legislature: the body approved all of the recommendations, but did not fund them (Oyster Farmer 3 2022). This disconnect–wherein elected officials recognize the expertise of well-informed stakeholders in the oyster farming industry, but fail to implement their ideas in concrete policies–is a recurring theme (Oyster Farmer 3 2022). One current and especially fraught example of this dynamic is the moratoria that block oyster farming in certain water bodies in North Carolina (Oyster Farmer 3 2022). Due to water quality concerns, DMF has closed select water bodies to aquaculture, but put sunset clauses on these moratoria so as to give DMF time to figure out how to avoid NIMBY—"not in my backyard"—lawsuits in the future (Oyster Farmer 3 2022). Several of these sunset clauses have since come and gone but the moratoria are still in place, so oyster farmers still cannot locate their leases there (Oyster Farmer 3 2022). NC shellfish growers–especially the smaller ones–would welcome intervention on this legislative issue and others by the Shellfish Growers Association, but after serving as the central hub for growers in the past, the organization has been relatively dormant in recent years, which hampers the advancement of the industry

(Oyster Farmer 2 2022). Oyster growers by themselves can struggle to compete for the ears of the legislators, who are likelier to heed and cater to landowners, as they often have more wealth and influence than smallholder farmers (Oyster Farmer 2 2022).

Despite many actors in the space, lease approvals hinge on local neighbors' user conflicts. If a given shellfish lease is environmentally safe and the paperwork is in order, the main impediment to establishing the farm is typically the opinions of the neighbors, i.e. NIMBYism. As will be detailed in the Economic and Legal sections of the PESTEL analysis, North Carolina limits the number of acres in a given oyster lease, as well as caps the number of total acres that can be registered to any given individual (North Carolina General Statutes § 113-202). In Virginia, not only are there no such limitations, but also the state allows people to rent the actual ocean bottom to farm instead of leasing the water column, which is the regulatory framework in North Carolina (NC Department of Marine Fisheries 2022). As a result of these different policy decisions, the largest oyster farms in Virginia extend to hundreds of acres, and it is extremely difficult for people interested in entering the oyster farming industry to find any available land to use (Oyster Farmer 1 2022). The advantage of Virginia's approach is that the shellfish production method is more out of sight, as oysters reside on the ocean bottom as opposed to in floating cages on the surface, like in NC (Aquaculture Economist 2022). This difference means that nearby landowners appreciate the water quality improvement, while also avoiding any alteration to their coastal view (Sea Level NC 2022). North Carolina shellfish farmers do not enjoy the same treatment due to their preference for container culture–growing oysters in cages instead of on the sea bed–and riparian landowners can and often do derail lease applications by airing their hostility at public meetings that are part of the permitting process (NC Department of Agriculture 2022). Shellfish growers have no choice but to engage with a myriad of private political forces, from recreational and commercial fishermen to duck hunters, HOAs, and many other local actors (NC Department of Agriculture 2022). Recreational fishers and duck hunters are significant drivers of policy and regulation because they bring a lot of money to the table, but often their preferences reflect no compromise whatsoever (NC Department of Agriculture 2022). For example, some duck hunters who have been hunting the same duck loads for decades or generations don't want anyone to get the lease for 500 yards in front of their impoundments, even though a shotgun only shoots 100 yards (NC Department of Agriculture 2022). Each part of the state is "its own community and part of the world," and communities are divided and strongly opinionated, to the point that "after enough time, someone won't talk to you because of your affiliation with another group" (NC Department of Agriculture 2022). Some residents have even referred to containers as "floating coffins" or invoked the "beaches of Normandy" when they find out a shellfish lease might be moving in (NC Department of Marine Fisheries 2022). Representatives from the Department of Agriculture who are invited to community meetings are acutely aware of this charged atmosphere and never speak off the cuff: they provide a formal statement and say nothing else, knowing that they can be put on the spot even by the people who invited them to the discussion (NC Department of Agriculture 2022).

DMF does help facilitate this part of the permitting process by making introductions between riparian landowners and new growers (NC Department of Marine Fisheries 2022). As much user conflict results from lack of communication and misconceptions, the personal relationships brokered by DMF often resolve the NIMBY issue (NC Department of Marine Fisheries 2022). DMF recommends that an aspiring grower "go knock on doors, go on your boat to talk to other growers in the area and learn what issues they deal with that DMF might not even know about, and ask the neighbors about the area—maybe they use that spot for tubing, but 100 yards away would be great" (NC Department of Marine Fisheries 2022). This intensely local and interpersonal undertaking stands in sharp relief against the other largely bureaucratic phases of the permitting process, e.g. when five agencies in addition to DMF examine the application, or when DMF conducts the Riparian Notification Process and sends certified letters to every landowner within 200 feet of the proposed lease (NC Department of Marine Fisheries 2022). In this way, the permitting process reflects some of the precepts of participatory planning, which is an approach that "involve[s] the entire community in the process of urban or rural planning in order to foster community development" (GIZ 2022). The rationales behind participatory planning are that citizen participation might make policies more reflective of residents' preferences, and that "the public might become more sympathetic evaluators of the tough decisions that government administrators have to make, and the improved support from the public might create a less divisive, combative populace to govern and regulate" (Irvin and Stansbury 2004). With such a crowded and contested coastline, getting growers and neighbors together to discuss how to share the space helps all the players "understand the important linkages and trade-offs that exist between their community's quality of life, social, economic and environmental assets" (Seitz 2001).

PESTEL - Economic

Industry strength is a composite of the practices of individual farmers. The key to whether a grower of any business size is successful or not is whether they adequately and appropriately frame and plan their business model. Gear type, production system attributes, growing on bottom or in containers, and desired scale are examples of important elements of the business to consider (Aquaculture Economist 2022). Whether to work full time or part time is one of the first decisions for a new grower; for instance, some people teach during the school year and grow shrimp and oyster to supplement their main income (NC Sea Grant 2022). As an industry, the growth of oyster mariculture in North Carolina is limited by two factors: the technology individual farms use to fuel their production, and the access to acreage for lease (NC Department of Marine Fisheries 2022). A properly run farm on even half an acre can be extremely lucrative—the demand for NC oysters inside and outside the state is high—but by the same token, a poorly run farm can waste a lot of money and resources and possibly contribute to marine debris in local waterways (NC Department of Marine Fisheries 2022). While it is true that economies of scale are real in aquaculture with smaller producers facing higher costs, there are profitable smallholder shellfish farmers throughout the US who have even survived the chaos and disruption of the pandemic (Aquaculture Economist 2022). That's good news for North Carolina, because the hallmark of the shellfish leasing program in NC is a focus on small growers. Statutes G.S. 113-202 require shellfish lease seekers to be NC residents—to keep economic gains and ownership of local waterways in the state—and individual shellfish holdings are limited to 50 acres per person (North Carolina General Statutes § 113-202), unlike e.g. Virginia, which has many growers who lease hundreds of acres apiece (NC Department of Marine Fisheries 2022).

Many small farmers don't pay themselves. Across both terrestrial and aquatic agriculture, it is common for producers not to pay themselves a wage. Many NC oyster farmers rely entirely on unpaid family labor and are often content with that arrangement, because their goal is to generate supplemental income—and if someone charged out all of the labor hours of their shellfish business, there would be no path to profitability (Aquaculture Economist 2022). But if the goal is to fully support a family through full-time oyster production, a grower must structure their business differently, with higher capital investments and more cash flow (Aquaculture Economist 2022). This goal is very difficult to reach, and many businesses fail at doing so (Aquaculture Economist 2022). In a similar vein, it is also challenging to transition from a small operation to a larger one, which is how most successful large farms approached their growth strategy (Aquaculture Economist 2022). Most people who farm oysters full time have a few employees, but labor is one of the many difficulties in scaling an oyster farm: the pool of potential workers is limited, especially when housing availability is taken into account (Oyster Farmer 4 2022) and when looking on the Eastern seaboard (Ferry Cove 2022). Within North Carolina in specific, many oyster farms are also situated in very rural areas with much lower population density and fewer people who are of proper age ranges for this type of work (Oyster Farmer 2 2022). Risk management too can be more difficult for small farms, because the cap on acreage per person means it is less possible to distribute risk from storm damage or water quality changes over multiple sites (MD Sea Grant 2022).

Marketing context varies by geography and firm size. Another common obstacle for smallholder American agriculturists is access to markets. In North Carolina, there are only two large-scale shellfish distributors, who are based on the coast (Dietz 2020). As it is not cost-efficient for growers to sell small quantities of their product at a time, this scarcity entails limited opportunities for NC growers to profit from their wares by securing large orders. The major oyster markets are in the Northeast, and Virginia has emerged as a leader in recent years and taken market share from the Northeast states, in the process also cutting out oyster growers in South Carolina who couldn't compete (Aquaculture Economist 2022). Maryland is rapidly developing its oyster industry as well to catch up to Virginia, and North Carolina is following Maryland's lead (Aquaculture Economist 2022). A little over 10 years ago, people figured out that by tumbling oysters, they could affect the shape of the product, so many developed specific half-shell oyster brands with unique names, like Bowling Ball and Fat Bastard (Aquaculture Economist 2022). Oyster restaurant demand spiked; oyster bars and trails took off, paired with wine; and people loved the variety and sought oysters from all over (Aquaculture Economist 2022). But before the pandemic hit, there were signs that oyster markets like Washington, D.C. and New York City were getting saturated; then COVID-19 struck and threw the industry into disarray (Aquaculture Economist 2022). Big producers on the East Coast had begun looking into developing inland markets in Chicago and St. Louis, but this option only exists for large growers, as they are the only ones with sufficient packing and cleaning facilities and logistical support for pandemic-disrupted supply chains to support cross-country shipping (Aquaculture Economist 2022).

Within North Carolina, local oyster sales depend mostly on personal relationships (Aquaculture Economist 2022), and small growers can struggle figuring out where to sell their product (MD Sea Grant 2022). Smallholder oyster farmers don't have the time, production volume, or money to pay someone to do deliveries to 15 different restaurants all over the state (MD Sea Grant 2022). Selling to a wholesaler can be a more attainable proposition, but then the questions are how a given smallholder grower gets on that distribution list, whether they can sustain the volume the distributor requires, and how to differentiate their product among so many competitors (MD Sea Grant 2022). Grocery stores also expect a consistent, sizable scale of production, because it's not worth their time otherwise (MD Sea Grant 2022). Depending on the area, someone could run a farm stand and take pre-orders, but that is a very location-dependent strategy (MD Sea Grant 2022). Following the same thread, in Maryland, the best route to profitability for oyster growers is vertical integration—starting with the farm, then an oyster bar, a full restaurant, and an additional mobile restaurant—but that requires vision, a receptive community, and considerable business acumen (Ferry Cove 2022).

Market availability for growers also depends on the type of production growers are engaged in: on-bottom versus container (floating cage) culture. Container culture offers the potential for higher profits, but it comes along with higher risks (Parker 2022, Engle et al. 2021). From an industry view, bottom culture is the path to volume production, and proposals are underway to expand bottom culture growing in North Carolina (Ferry Cove 2022).

The Community-Supported Fishery (CSF) model offers smallholder aquaculturists an option for both collective marketing and stable, recurring revenue with lower transaction cost. In a CSF, customers sign up and pay at the beginning of the growing season to get fresh-harvested orders of fish that they pick up each week (Salladarré et al. 2018). This model has worked for other foodstuffs, but the numbers don't compute for oysters: a grower would need to ship hundreds of boxes a week and work farmers' markets on the weekend to reach sufficient scale for profitability (Ferry Cove 2022). Another option is a cooperative, like the Watermen Cooperative in Maryland that brings together 21 watermen to produce and market shellfish as a group (Ferry Cove 2022). This method is viable in theory, and North Carolina even has the infrastructure to support it: several empty, abandoned fish houses along the coast with docking areas for boats and trucks could easily be retro-fitted for shellfish distribution, with one selected to be a central packing and storage hub, and then all that would remain is purchasing a few refrigerated vehicles for transport (Oyster Farmer 2 2022). In practice, though, the co-op approach is not in the offing for North Carolina, simply because many growers coming from the commercial fishing world are "salty dogs" who want to maintain solitary business practices like their forebears, and are not interested in this type of collaboration (Oyster Farmer 5 2022). Some of the younger people entering the industry are more willing to work together, but not enough to create a critical mass as of yet (Oyster Farmer 5 2022).

North Carolina statutes require oyster farmers to be NC residents, limit the number of acres that can be registered to an individual oyster farm parcel, and cap the number of acres an individual can possess across all of the parcels they own: a single farm must be between a half acre and 10 acres, and individual shellfish holdings must be 50 acres or less (North Carolina General Statutes § 113-202). These restrictions mean that NC has only smallholder growers, and no medium- or large-scale growers. While these prohibitions keep firm size manageable and maintain local control of the industry, they also prevent smallholder growers from gleaning any positive externalities from the practices of larger growers, e.g. joining their distribution routes or equipment orders (Oyster Farmer 2 2022). Even the smallholder growers who have managed to scale their businesses identify gaps that would be served by more production coordination among growers—for example, sharing equipment would defray some of the costs of capital acquisition, free up cash for expanded production, and provide some protection against depreciation (Oyster Farmer 5 2022).

Because most growers have their own brand name and want that name to follow their product, it is difficult for farmers to help each other fill orders (Oyster Farmer 2 2022). Oyster farmers used to have more control over the price and use of their products, but now many NC growers in the area are selling to the same restaurants, so they need to find other distributors they trust or move west (Oyster Farmer 2 2022). But in addition to the expectations of consistent volume and quality as well as the difficulty of product differentiation, distributors also can add the challenge of price squeezing (Oyster Farmer 2 2022). Young people entering the industry who are comfortable with Direct-to-Consumer (DTC) eCommerce shops and social media marketing are better positioned to avoid being at the mercy of the market than those who rely on distributors or selling to a limited and well-supplied set of restaurants (Oyster Farmer 2 2022). Outside of marketing, though, there are many ways that oyster farmers collaborate. Farmers speak frequently on the phone, take part in convening organizations like Oyster South, attend yearly seminars, and share ideas about production and handling regulations (Oyster Farmer 1 2022).

Growth phase and prospects for NC oyster industry unclear. In the past five to ten years in North Carolina, there has been an exponential increase in applications for oyster farming permits, especially those of the water column variety (NC Department of Marine Fisheries 2022). First Hurricane Florence in 2018 and then COVID-19 in 2019 hampered the industry's growth in the state. Florence and Tropical Storm Michael almost wiped out the entire industry with losses of nearly $10 million (Incremona 2019), but the industry doubled down afterwards—instead of taking their insurance payouts and walking away, many farmers re-invested the payouts in their farms and grew their businesses and thus the industry (NC Sea Grant 2022). As the industry recovers, many oyster growers recognize the increasing competition, but see the NC market for oysters as exponential and far from saturated (Oyster Farmer 5 2022). Following the explosion of the industry in Maryland and Virginia—for reference, the value of shellfish alone in VA is $50-60 million, which is comparable to the whole aquaculture industry of NC—many MD and VA growers moved to NC to take advantage of available habitat for shellfish production (NC Department of Agriculture 2022). Within the state, commercial fishing families in Eastern North Carolina are diversifying into shellfish to escape regulations like catch limits and earn more revenue (NC Department of Agriculture 2022).

North Carolina's oyster businesses are hampered by several widely recognized constraints. Despite much to celebrate in the North Carolina oyster industry, there are still several gaps that need to be addressed to unleash stronger growth. The state has very few oyster hatcheries, which means it is difficult for growers to acquire seeds—and if growers bring in seed from out of state, they must submit samples to DMF for disease testing and be approved for import permits (Oyster Farmer 5 2022). Growers would benefit from the establishment of a commercial hatchery in North Carolina, to supply sufficient seed as well as to create NC-specific family lines of oysters (UNCW Shellfish Research Hatchery 2022). Hatcheries in other places like Maryland have struggled to secure sufficient shells for their operations (UMD Horn Point Lab Oyster Hatchery 2022), but North Carolina does not have this problem, as it boasts a natural oyster fishery and an ocean bottom in good shape (Ferry Cove 2022). Some growers contend that the availability of free or low-cost oysters to put on a lease is the most powerful measure that the state could implement to boost their businesses (Ferry Cove 2022).

The lion's share of the conversation about how North Carolina could support oyster farmers centers on forms of financial support: start-up funding, investment capital for expansion and equipment expenditures, risk management vehicles, and properly comprehensive insurance coverage (North Carolian Coastal Federation 2021). Many people are very passionate about oyster farming, but may not have access to the resources they need to do it profitably, leaving them with the feeling that they are running a "heavy, sharp rock farm" (MD Sea Grant 2022). Maryland offers a unique financing program to shellfish growers called MARBIDCO, which has a part-loan, part-grant format that forgives the principal loan to help farmers get going (MD Sea Grant 2022) and is locally catered (Ferry Cove 2022). If a new farmer needs to borrow $100,000 before growing any oysters, their first crop may not yield many oysters, and they may need to pay back the loan before the oysters have reached maturity—but if the farmer has no money left, they can't buy the equipment necessary to expand the operation and make enough revenue to make good on the loan, so that means many farmers start out with too few oysters on their lease to hedge the risk (MD Sea Grant 2022). A program like MARBIDCO could potentially be a boon in North Carolina and has been recommended in both the Oyster Blueprint and Vision to 2030 state oyster planning documents (Fodrie et al. 2018, North Carolina Coastal Federation 2021).

The success of such a program, however, depends on its funding and administration (Aquaculture Economist 2022). If the state finances someone with a bad business plan because it wants to expand the industry, the failure of that enterprise will damage the whole industry; if instead, a low-cost financing program is combined with financial training and assistance and realistic milestones that the business has to meet along the way, it will be much more successful (Aquaculture Economist 2022). The Oyster Blueprint recommends a business specialist position be added at NC Sea Grant, but it places that recommendation in Year 5 and the financing program in Year 1 (North Carolina Coastal Federation

2021). North Carolina’s wide sphere of oyster farming stakeholders could note Maryland’s example and consider changing the order of implementation of the identified priorities in order to realize the gains from the funds as well as the financial planning and oversight.

Across the country, there are many states in which different stakeholders’ incentives for developing aquaculture are not as well aligned as they are in Maryland. Arkansas is an illustrative example: the state manages a program that provides federal financing at low rates for aquaculture farmers, but the business projections provided by program applicants are often overly optimistic and not realistic (Aquaculture Economist 2022). The state ends up funding many operations because of political reasons instead of practical economic reasons, and several end up folding, which amounts to a waste of federal tax dollars (Aquaculture Economist 2022). Meanwhile, other business plans that are viable and submitted by entrepreneurs with experience are not funded because their projections don’t seem profitable enough (Aquaculture Economist 2022).

Insurance is often the next-highest priority for those hoping to support NC oyster farmers. A grower can face six figures of cost just for gear, and a hurricane can destroy a large swath of it in one event (Oyster Farmer 4 2022). Small farms need a line of credit for purchasing gear, especially as it is another necessary up-front investment that happens 9-13 months before any oysters are fully mature (Oyster Farmer 3 2022). This topic is “kind of heated” in North Carolina and it’s not completely clear why the state has yet to secure its oyster farmers loans at low prime (Oyster Farmer 3 2022). Both the Oyster Blueprint and the Vision to 2030 document make this recommendation as well (Fodrie et al. 2018, North Carolina Coastal Federation 2021).

Beyond gear, the insurance options for small growers’ general operations are also meager and few. The US Department of Agriculture offers the NAP insurance program, which growers purchase because it is cheap, and because those who have been in business for less than ten years get reduced rates on the basic plan's premium (MD Sea Grant 2022). This program does not make farmers whole, however—it is only for catastrophic losses, and even then, it is also worth it for growers who have received the payout to hire an auctioneer to liquidate any remaining farm assets (MD Sea Grant 2022). Some groups are working on developing a good insurance product for oyster farming, but nothing exists as of yet (MD Sea Grant 2022). The USDA is also developing a new shellfish risk management program to replace the current, relatively weak one, and depending on the final structure of that program, it could make huge long-range improvements to the viability of the industry as a whole (NC Department of Agriculture 2022).

Whatever the North Carolina government chooses to do to augment the state's shellfish industry, its actions should complement those of other actors in the space. For example, for several years, the NC Coastal Federation has been working on the idea of "Shellfish Incubators," with the first site poised to open soon on Harpers Island in Carteret County (Oyster Farmer 3 2022). These Incubators would provide places to refrigerate product and function as hubs for oyster farmers in NC, helping address infrastructure and aggregation needs to improve market access for smallholder growers (Oyster Farmer 3 2022). The graduate school at UNC-Wilmington hosts a Marine Science lecture series, Carteret Community College offers a Shellfish Farming Certificate Program, and NC Sea Grant teaches a Shellfish Farming Academy (Oyster Farmer 5 2022). These programs can and do benefit from partnering with the state, and with expansion, could assist even more growers in knowing what they're getting into, understanding nursery requirements, and exploring business practices (NC Sea Grant 2022). One pending example of such collaboration is the current discussion between NC Sea Grant and DMF to establish a state-wide oyster mariculture training certificate, whose requirements not only Sea Grant but also community colleges like UNC-W could fulfill (NC Sea Grant 2022). Demonstration-focused support can be even more useful to new growers than low-cost financing in some cases: for example, many fishers prefer making purchases with cash instead of loans, so they might not even use a loan program were it to be established (Ferry Cove 2022). The decisions of which options for the state to prioritize depend on the target audiences that the state would like to encourage to pursue oyster farming (Ferry Cove 2022).

Oyster farmers want to be paid for the additional benefits oysters provide to the environment. For the future, one interesting area of potential state support for oyster farmers could be paying oyster farmers for the additional ecosystem benefits that their operations provide to the state at large. One proposal that has been floated is a nutrient mitigation payment program (North Carolina Coastal Federation 2021), where farmers are paid for the cleaner water provided by their oysters, a single one of which can filter 50 gallons of water a day (Oyster Farmer 1 2022) and remove harmful chemicals like nitrogen. Two such programs currently exist, in Virginia and in Maryland (Rose et al. 2021). Another idea is to pay farmers for carbon sequestration as their oysters create their shells (UNCW Shellfish Research Hatchery 2022). The concept of paying oyster farmers carbon or nitrogen credits is being explored at this year's NC Oyster Aquaculture Development Conference in New Bern, and growers are interested even if the credits were not monetarily significant (Oyster Farmer 2 2022). If the credits only covered the seed oysters that growers must purchase every year, or even if the credit were just by word of mouth that farmers are doing something good for the state, farmers would enjoy the recognition and appreciation (Oyster Farmer 2 2022). Other similar opportunities to pay oyster farmers are for recycling shells that can be used to enlarge oyster reefs, or valuing and compensating farmers for the juvenile blue crab habitat their farms provide (Oyster Farmer 1 2022).

PESTEL - Social

Consumer demand for seafood is shaped by price, consumer income, and societal health concerns. When seafood prices are too high, consumers demand less farmed seafood as well. Instead, they opt for proteins such as chicken, pork, beef, and non-meat proteins (Madigan 2021). Consumer income also plays a role in determining the demand for farmed seafood. Since seafood is generally more expensive than other options, demand for it will decrease at lower income levels. Health concerns have also pushed consumers to consume more seafood. Since seafood is perceived to be a healthier source of protein and can be used as a substitute for other proteins, consumer demand has been resistant to changes in price (Madigan 2021).

Marketing is a crucial aspect of a successful business, and storytelling can be used to build social bonds that attract customers. In North Carolina, and especially along the coast, oyster farmers can promote their oysters as local and their farms as family-owned, and use storytelling to more effectively market their oysters. Some consumers care about buying local and enjoy feeling a sense of connection to the products that they purchase. Storytelling can be used to appeal to those customers; the North Carolina Oyster Trail relies on it to promote these features of North Carolina oyster farms (NC Oyster Trail). The Trail offers tours of local shellfish farms to give tourists unique experiences, markets the distinct flavors of local oysters, and advertises the local oyster lore. At the same time, oyster farmers cannot focus solely on the local aspect of oysters: some customers care more about the price (Sea Level NC 2022).

NIMBY resistance and other community perspectives shape the siting experience. In addition to the factors that affect consumer demand, there are social forces that either allow or prevent new oyster farmers from entering the industry. For example, in the siting process, stakeholders may oppose the leasing and establishment of a new farm if it is considered an eyesore and local community members may be against having an oyster farm "in their backyard" (NC Department of Agriculture 2022). Social dynamics vary between potential sites, depending on the density and assortment of stakeholder groups jockeying for use of the space. Therefore, it is important to build a deep understanding of the local community and forge strong relationships with possible future neighbors.

Societal trends also influence the profile of oyster farmers who are entering the industry. With the drop in fish stock, a portion of the new oyster farmers were previously fishers who are now looking for supplemental or new streams of income (NC Sea Grant 2022). Although oyster farming differs from fishing, there are still some transferable skills that can help this group of new oyster farmers succeed in the industry. On the other hand, another group of new entrants has emerged that does not have a fishing background (NC Sea Grant 2022, Oyster Farmer 2 2022). This group comes from a variety of backgrounds and they may be doing oyster farming just as a hobby, or may be starting a farm after retirement (NC Sea Grant 2022, Oyster Farmer 2 2022). This second group may bring a different set of skills from their experiences or previous work experiences (such as familiarity with running a business, working with technology, or experience with marketing), but may lack hands-on knowledge and skills.

PESTEL - Technological

Technology plays an integral role in oyster farming, from initially determining the location of the farm to optimizing production throughout the season, and from optimizing oyster genetics to utilizing technology for marketing and sales. An aspiring oyster farmer must first use satellite imagery and geographic mapping tools to determine the optimal site for an oyster farm (Lease FAQs). This location must have no submerged aquatic vegetation (SAV), protection from potential hurricanes, isolation from stormwater runoff, and favorable salinity to optimize oyster growth. Since oyster farm leasing is not permitted in areas with SAV, accurately identifying and avoiding these areas for site selection can expedite the permitting process. High floods from storms and winter tides can result in bouncing cages and destroyed gear that ultimately kills the oysters (Incremona 2019). Using GIS to identify optimal locations that may be shielded from potential storms and other natural disasters would benefit aspiring oyster farmers. Stormwater runoff also presents a problem, as it can lead to massive die-off events and financial losses.

After finding an optimal location and going through the permitting process, the oyster farmer needs specific equipment, such as a boat, upweller, growing cages/bags, and moorings, depending on whether they choose to farm on the ocean bottom or in floating cages (Oyster Farmer 4 2022). While there do not seem to be significant innovations in the basic gear necessities and growing methods, new technology has been developed to improve oyster cleaning, sorting, and packaging efficiency (Oyster Farmer 5 2022). These tools are discussed in more detail in the Tools Summary and Analysis Section.

Genetic modification to enhance animal resilience and increase growth rate is also a promising area for development in the future (Madigan 2021). In the past, triploid oysters were bred by crossing tetraploid and diploid oysters (Finelli 2021). Oyster farmers tend to grow only triploids, because these oysters focus energy solely into growth rather than reproduction, allowing them to grow at a much faster rate (Finelli 2021). However, recent oyster mortality events have mainly affected triploid oysters (Finelli 2021). The University of North Carolina at Wilmington has a program that studies oyster genetics and is researching the cause of these mortality events (Finelli 2021). If genetic modification can mitigate oyster mortality events, it can prevent massive financial losses for oyster farmers.

Technology also plays a role in the processing of oysters for sale. New programs and machines have been developed to track oyster growth and clean and package oysters (Oyster Farmer 5 2022). These technologies increase efficiency and can allow oyster farms to scale up. In addition, social media must be used effectively for marketing and logistical purposes. These technologies and tools are discussed more in depth in the Tools Summary and Analysis Section below.

The IBISWorld US Fish & Seafood Aquaculture industry report cites access to the latest available and most efficient technology and techniques as one of the key success factors for the shellfish aquaculture industry moving forward. Having access to new technology and being able to adapt to the local ecological environment will improve the oyster farmer’s expertise and ultimately increase output efficiency (Madigan 2021).

PESTEL - Environmental

Oysters enhance the ecological context where they grow in many different ways. Especially in the age of the climate crisis, it is vital to find ways to protect, stabilize, and nourish the natural environment. In North Carolina, sea level rise, coastal erosion and inundation, and pollution of waterways are all pressing concerns. According to NOAA, oysters have several benefits to the local environment (Office of Habitat Conservation 2021). Oysters are known to filter water and remove excess nutrients and other particles, which improves water quality. They also absorb chemicals such as carbon, nitrogen and phosphorous; a 2015 study demonstrated that oysters removed 15.2, 6.2, and 0.2 tonnes per year of carbon, nitrogen, and phosphorous, respectively, from a 28-hectare area (Cerco 2015). Oysters also help with carbon recycling by taking in and storing atmospheric carbon that has dissolved into the water (Fodrie 2017). In addition to filtering the water of various particulate matter, oyster shells can create reef-like structures, which provide habitat for other marine life (Office of Habitat Conservation 2021). These reefs can offer storm protection by acting as a protective barrier against increasing sea level rise and increasing intensity and frequency of storm impacts, as a result of climate change or otherwise (Johnson 2014). Since responsible oyster farming is beneficial for the local ecosystem, a small-scale oyster farm can market its business as environmentally friendly and attract consumers who care for the environment. Furthermore, oyster shells have many end-of-life applications across "water treatment, CO_2 capture, building materials, reef restoration, agricultural supplements, high-tech polymer manufacturing, catalysis, and biodiesel production" (Bonnard 2019).

Environmental impacts of oyster mariculture vary based on several farm-specific factors. While farming oysters in the ocean can have powerful positive impacts like reducing water contamination and building habitats for oysters, algae, crabs, and fish, those practices are not a given with every farm, and also must be viewed in the context of other considerations, like what gear, harvesting methods, chemicals, and cleanup plans farmers apply (Musselman 2021). The environmental impacts of the materials used for gear, the recyclability/reuse of that gear, and the potential for lost gear as marine debris must be taken into consideration towards the environmental impact of oysters (Tamburini et al. 2019). During the fattening, pre-fattening, and harvesting stages, the use of diesel fuel in boat transportation can cause up to 74% of total environmental impacts across the oyster's life cycle (Tamburini et al. 2019). Compared to landfill deposition, shell recycling programs can decrease carcinogens, ecotoxicity, respiratory inorganics, and effects from climate change (Majewski et al. 2020). The distance to landfill, compared to the distance to the processing center, plays a significant role in the degree of environmental benefits (Majewski et al. 2020). Overall transportation distance is a major factor to consider towards achieving environmental benefits. Shorter supply chains yield environmental benefits, but can be outperformed by longer supply chains that deliver higher relative volumes of oysters to mid or end points (Alvarenga et al. 2012). The distance of supply chain, type of vehicle used and vehicle weight efficiency must all be taken into consideration when trying to maximize the environmental benefits of oyster mariculture (Alvarenga et al. 2012).

Submerged Aquatic Vegetation (SAV) is a flashpoint between oyster farmers and resource managers. SAV provides crucial habitat to aquatic species in sounds and estuaries, so oyster farmers are statutorily prohibited from creating a farm in an area with significant historical or current presence of SAV (Blackburn 2015, NC Department of Marine Fisheries 2022). While this restriction is not new, some of the areas now seeing SAV growth are new; the reasons for the habitat flux are not fully understood (NC Department of Marine Fisheries 2022), but farmers are extremely frustrated when otherwise pristine oyster growing waters are closed for this reason (Oyster Farmer 2 2022). The rationale for the restriction is the belief that oyster farming suppresses the growth of SAV by blocking light penetration into the water–but many studies making this claim look only at the area directly under floating cages, and not in any other locations on oyster farms (Blackburn 2015). Some growers even see evidence on their farms of increased SAV presence (Oyster Farmer 2 2022, Oyster Farmer 4 2022): for example, one farmer noted that his gear catches uprooted SAV "as it floats by, allowing it to drop seeds right there at his facility instead of floating on into deeper waters where it can't grow" (Blackburn 2022).

PESTEL - Legal

Small farms are the only allowed size in the NC oyster mariculture industry. As detailed in the economic section of the PESTEL analysis, North Carolina has exclusively small oyster farms and businesses, and that is completely intentional and by design (NC Department of Marine Fisheries 2022). The statutes that require NC residency and limit individual shellfish holdings to 50 acres a person and 10 acres per site represent pointed policy decisions to protect smaller operations from being pushed out by bigger ones (NC Sea Grant 2022). Half an acre is the minimum size required by statute, and though there are farms of many different sizes throughout the state, the average is 3-4 acres (NC Sea Grant 2022). The low acreage reflects the preponderance of hobby farms in the industry, where oyster farming is a secondary income source—but plenty of these outfits still sell products in restaurants and seafood markets (NC Sea Grant 2022).

Permitting is major and widespread issue, especially the slow pace. In the shellfish world, the most severe and pervasive problem—regardless of where you look, in Maryland, Maine, North Carolina, or California—is permitting (Aquaculture Economist 2022). The types of resources available to help farmers through the permitting process differ by state, including state agencies (with varying degrees of data maintenance), land-grant universities, and state aquaculture associations (Aquaculture Economist 2022). Across the highly heterogeneous landscape of states, the significant challenge with permitting is the delay; if it takes years to secure a lease, a potential grower is losing investment money that whole time, meaning that only part-time growers can really afford to wait out this period (Aquaculture Economist 2022). Shellfish growers across the country, including in North Carolina, clamor for faster, clearer permitting processes (Aquaculture Economist 2022).

According to state law, the waters of North Carolina are held in "public trust" (NC Department of Marine Fisheries 2022), meaning they belong to all the residents of the state equally. DMF is charged with defending the "public trust" use of the waters of the state, but nowhere in the law is "public trust" defined or described. From the perspective of NC's Department of Marine Fisheries, the permitting process is slow because each lease represents a piece of public-trust water that's been privatized (NC Department of Marine Fisheries 2022): in essence, DMF must ascertain that an oyster farm is the best use of a given patch of water over any other possible uses. A fairly rigorous permitting process is necessary, because these leases last for ten years (NC Department of Marine Fisheries 2022). With that said, even DMF perceives that the statutes that specify the permitting process have several problems. First, the statutes are not very plastic, and it is difficult to re-open and adjust them after they've been passed (NC Department of Marine Fisheries 2022). Second, legislators are not experts in marine resources and ecological issues (NC Department of Marine Fisheries 2022). Third, NC has been authorizing leases since the 1800s, so there is some antiquity built into the industry (NC Department of Marine Fisheries 2022). Fourth and most thornily, the statutes stipulate that shellfish leases must be "compatible with public trust use," but don't define what that entails (NC Department of Marine Fisheries 2022).

In 2019, DMF began working on Shellfish Enterprise Areas/Zones (SEA/Zs), a pilot project to ameliorate some of the difficulties of the permitting process. SEAs are a framework that's been used in other states like Florida to provide large chunks of pre-permitted leases to which growers can apply for a sub-lease: instead of taking a year for the permitting process to be completed, it could be finished in just a few weeks (NC Department of Marine Fisheries 2022). Aggregating leases might also attract and nurture other supply chain sector businesses, like an oyster gear manufacturing and repair service business (Harrison 2019). DMF is attempting to work out several issues in this pilot project. Most notably, it's almost impossible to find a 50-acre lease without user conflicts, as most places with low user conflict are low feasibility for aquaculture (NC Department of Marine Fisheries 2022). Relatedly, if many leases are packed near each other, there is the possibility of condensing user conflict around shellfish (NC Department of Marine Fisheries 2022). DMF is currently gathering information, considering locating SEAs in the four shellfish growing moratorium areas or elsewhere, and conducting public meetings (NC Department of Marine Fisheries 2022). DMF has not consulted growers yet: right now they are talking to town officials and municipalities around Boat Sound—one of the moratorium areas—and then they will go to stakeholder user groups outside the growers (NC Department of Marine Fisheries 2022). If those other groups won't approve the idea anyway, there is no need to solicit the input of growers; farmers' insight will be valuable once the social license from the public to operate is secured, and the main topic to discuss is program structure (NC Department of Marine Fisheries 2022).

Once DMF reaches the point of contacting growers for their perspectives, they might encounter several points of dispute. Pamlico Sound, one area currently being prioritized for SEAs, is not close to where the majority of farmers are (Oyster Farmer 3 2022). The western part of Pamlico County is also very rural, with "more bears than people" (Oyster Farmer 2 2022), a challenge for farmers who want to avoid living in the middle of nowhere and instead seek to locate somewhere cosmopolitan and close to the market. Moreover, farmers tend to prefer closed, private areas away from other farmers and safe from any risk of theft (Oyster Farmer 3 2022). From a planning perspective, too, these SEAs would expire in 5-10 years, and farmers might be forced to move after that period (Oyster Farmer 3 2022). SEAs are a promising undertaking by DMF to address the major issues with the current permitting regime, but they are by no means a panacea, and there are still many open questions concerning their design and implementation.

Farmers chafe at regulations they perceive as cumbersome. Beyond the notorious permitting process, oyster farmers view the thicket of regulations surrounding aquaculture as onerous and ever-changing. Recent additions include requirements for bird deterrents and tracking of how much time each individual oyster spends out of the water (UNCW Shellfish Research Hatchery 2022). Growers recognize that rigorous regulations benefit health, food safety, disease control, and more, but many are frustrated that the aquaculture business regulatory environment in the U.S. is “convoluted, redundant, and inefficient” in accomplishing those goals (van Senten et al. 2020). The onus is on the state officials to streamline inter-agency collaboration, educate lawmakers, and liaise with the federal government in order to maintain these achievements but lower their compliance cost for growers.

DMF primarily handles NC oyster farming, but some farmers think NCDA would be a better fit. On the note of state agency teamwork, many NC growers are confused about why DMF instead of the NC Department of Agriculture is the head agency in oyster farming regulation. In North Carolina, oyster farming is a “weird stepchild” between DMF and the NCDA (Oyster Farmer 4 2022): DMF is a resource management division, not an agriculture division like the NCDA, and they try to manage shellfish farmers like a wild resource (Oyster Farmer 2 2022). For example, oyster farmers must abide by oyster size limits even when they buy their own seeds (Oyster Farmer 2 2022). Oyster farmers recognize that the department is resource-limited and statutorily obligated to perform these functions (Oyster Farmer 2 2022), but see a disconnect between the design of the agency and this particular role. Furthermore, NCDA and its Extension boast prolific resources: DMF has a budget of $2 million, versus one of $2 billion at NCDA (Oyster Farmer 5 2022). With that said, making this legal change would be difficult–the state legislators would have to be convinced first, and no governmental agency likes to cede responsibilities–and it is impossible to know in advance whether the environmental oversight of NCDA would be sufficiently stringent to maintain the current marine ecological health that DMF targest.

Table 1: PESTEL Summary and Highlights

P - Political	• Despite many actors in the space, lease approvals hinge on local neighbors' user conflicts • Interest in and evidence of government agency collaboration varies widely by state, moderate in NC • Local and non-local interest groups active in mariculture • Efforts to reform the permitting process involve complex politics that evolve over time
E - Economic	• Many small farmers do not pay themselves • Industry strength is a composite of the practices of individual farmers • Marketing context varies by geography and firm size • Growth phase and prospects for NC oyster industry unclear • North Carolina's oyster businesses are hampered by several widely recognized constraints • Oyster farmers want to be paid for the additional benefits oysters provide to the environment
S - Social	• Storytelling is an effective method of marketing • NIMBY attitudes within communities can be a major barrier to new oyster farms • Various backgrounds of new oyster farmers show trends in behavior and skills
T - Technological	• Satellite imagery and mapping tools are important developments for the first crucial step of siting • Genetic modification for growth and resiliency could help mitigate oyster die-off events and associated financial losses • Apps and machines for operations and processing can help increase efficiency and profits
E - Environmental	• Practices of individual oyster growers impact environmental footprint of oyster farming • Oysters benefit the environment through carbon absorption and water filtration • Oyster shells create reef-like structures that provide habitat for other wildlife • Submerged aquatic vegetation is a barrier to establishing new oyster farms
L - Legal	• Small farms are the only allowed size in the NC oyster mariculture industry • Permitting is large and widespread issue, especially the slow pace • Farmers perceive regulations as cumbersome • DMF primarily handles NC oyster farming, but some farmers think NCDA would be a better fit

PESTEL Summary

After completing a well-rounded analysis of the factors affecting the oyster industry in North Carolina, our findings suggest that overall, the oyster mariculture industry is well established and is well-positioned; however, there are still some areas that could be improved. On the political side, permitting has been a recurring issue. The permitting process itself can be challenging to navigate, and added pressure from local NIMBY attitudes can make the process more frustrating. From the economic view, the different state programs that support oyster mariculture could be structured and prioritized differently depending on the backgrounds and preferences of the oyster farmers who are entering the industry. An interesting take-away from the social analysis is the potential for using storytelling and marketing to drive sales with consumers who want to learn more about the local farmers. Regarding technology, there have been developments in siting, marketing, genetic modification, and oyster sorting and packaging efficiency that can be used as tools by oyster farmers entering the industry and growing their businesses. For the environmental dimension, oysters are generally seen as beneficial for local ecosystems, because they filter the water and their shells provide habitat for other marine creatures. This benefit could be turned into an incentive for new growers, if some type of carbon credit or blue credit were to be developed for oyster farmers in the future. Finally, from the legal vantage, oyster farmers may be better suited to fall under the jurisdiction of NCDA instead of DMF, as there is plenty of interplay between mariculture and terrestrial agriculture with respect to insurance and risk vehicles–but making this change would require convincing state legislators, mollifying DMF about their reduced responsibilities, and assuring environmental advocates that NCDA would sufficiently protect marine ecological health, the way DMF does.

Tools Summary and Analysis

In addition to the analysis of the various factors that affect the oyster industry, we conducted a landscape analysis within the industry to better understand the existing tools for new oyster farmers. In addition, we wanted to compile the tools, give recommendations on how to use them, and identify ways to fill any gaps. New oyster farms could take advantage of the variety of tools to help them navigate the process of starting and running a successful farm. This section will discuss some notable tools we came across in our interviews and research, discuss their pros and cons, and give recommendations to optimize usage.

Siting

Identifying the optimal site for the oyster farm is the first step to starting an oyster farm. There are two tools to help with site selection, the University of North Carolina at Wilmington (UNCW) Siting Tool and the Department of Marine Fisheries (DMF) Siting Tool. The UNCW tool provides more scientific information, such as water salinity, ocean bottom type, and ocean bottom depth. The information may be outdated, as the last update was in 2021. On the other hand, DMF's tool provides more policy information, such as areas limited by various moratoria and areas with existing leases and nurseries. This data is also regularly updated, usually within 48 hours of any changes (NC Department of Marine Fisheries 2022). The tools overlap on other types of information, such as submerged aquatic vegetation, oyster sanctuaries, and artificial reefs.

Because each of the two tools provides some unique data, it is important to consult both when identifying where to locate an oyster farm. Physical characteristics of the water, such as salinity and ocean bottom depth, are crucial to consider, while policy-related information is also necessary to determine where an oyster farm would be permitted.

Financial Modeling

Financial modeling can help a new oyster farmer to understand what scale to start at, how to maximize profitability, what growth rate to expect, and how to account for potential risks. From interviews with experts in the industry, there are two main financial modeling tools that stand out.

North Carolina Sea Grant has developed a Profitability Assessment Tool as a part of its Lessons in Mariculture lesson series (Lesson 10: Assessing Profitability of a Mariculture Operation). While the curriculum is developed by NC Sea Grant, the financial model is created by the Virginia Institute of Marine Science (VIMS). As a result, the cost of gear, oyster seed, insurance, and other supplies may differ slightly from the numbers that are already in the tool. However, the tool is easy to use and is much more robust than building a new model from scratch. The other lessons in the NC Sea Grant Mariculture lesson series also provide a strong foundation for a new oyster farmer, with thorough lessons and worksheets.

Industry experts also recommend the University of Minnesota Center for Farm and Financial Management Agriculture Plan. This tool allows users to build their own business plans and provides tips for the user to develop the most tailored plan for their situation. It is user-friendly and also free with registration (Engle 2021). While this tool is more directed towards terrestrial farmers, it can be repurposed and adapted for aquaculture purposes. In addition to general financial planning, this tool provides guidance for one’s career, self-development, insurance, investment, and debt reduction planning. Users can view sample plans and access worksheets from other organizations as well.

Planning, especially financial planning and modeling, is a crucial step for new oyster entrepreneurs, as it sets the foundation for the entire business. Since the University of Minnesota Agriculture Plan has more resources from other organizations and universities centralized in one location, a new oyster farmer may find it helpful to follow this plan first before switching to the NC Sea Grant tool for the financial plan.

Oyster Raising/Tracking/Cleaning/Packaging

There are several pieces of equipment and software that oyster farmers mentioned throughout the interviews. These tools range from being relatively cheap and makeable at home to pieces of equipment costing hundreds of thousands of dollars in the marketplace. Each tool plays its own role within the operations of an oyster farm.

The Floating Upweller System, or FLUPSY, is a piece of equipment that promotes oyster seed growth by protecting them from predators while increasing water flow and nutrient uptake. While it is possible for an oyster farmer to operate without a FLUPSY, it is low-maintenance while providing high return, making it a worthwhile investment despite the price ($10,945) (Floating Upweller System (FLUPSY)).

The SmartOyster tool helps collect data so that agriculturalists can farm smarter and operations can run more smoothly. The tool maps out the farm, tracks oyster stock and where it is on the farm, and lists upcoming maintenance activities. It also displays all the data and analytics in an easy-to-understand visual format. SmartOyster is a subscription-based tool, and the cost varies from $75-375 depending on the farm size.

The BlueTrace tool–previously called OysterTracker–simplifies the tracking and tracing of oyster shipments. It allows farmers to log their harvest, track the required information on waterborne bacteria such as Vibrio to prevent public health issues, and print shellfish tags. These tags streamlines the lot-to-lot tracing process and complies with ever-changing regulations. The cost of the tool is unclear.

Finally, the Pearlception machine massively increases sizing, sorting, cleaning, and packaging efficiency. The machine can self-load oysters for laser grading, before using air nozzles to move oysters to the correct station for packaging. The accompanying OysterLogic program tracks oysters and guarantees the oyster count. The Pearlception can grade, sort, and package more than 6,000 oysters each hour.

While these tools can significantly increase output efficiency, new oyster farmers do not necessarily need all of them to be successful. After establishing a new farm, we recommend the FLUPSY as the first step, since it provides a high return for its price. As the farm grows, we recommend the SmartOyster tool to help mitigate growing pains. The Pearlception may be an option for farms that have a different business model from scaling up so much. However, even then, it may be better for several farmers to purchase it together, so that they can share it and minimize equipment idling time.

Marketing/Selling

New technology plays a crucial role in advertising oysters and identifying new markets. During the COVID-19 pandemic, some oyster farmers were able to take advantage of social media platforms such as Instagram and Facebook to establish sales by directly shipping to consumers or finding ways to market undesirable oysters.

Life Cycle Analysis

In order to better understand and quantify the inputs and outputs across the value chain of oyster farming, a life cycle analysis can be used. A life cycle analysis is a methodological approach to quantify the total impact of a product, service, process, and/or system (Jolliet 2016). An LCA will generally provide insights into what products or systems contribute towards the highest percentage share of environmental impacts. They can be used to isolate a particular product or system, and/or compare alternate systems to gain similar insights into how and why each process causes higher environmental impacts.

Goal and Scope Definition

The aim of our LCA research was to identify environmental benefits and gaps in oyster mariculture, understand the current state of oyster mariculture practices in North Carolina, and highlight opportunities for improved environmental outcomes as the industry grows. Three stages of oyster mariculture were analyzed: (1) birth to harvest, (2) distribution, and (3) end of life. All three stages will reference existing LCAs, which will inform our discussion and recommendations. The Functional Unit (FU) across the LCA categories is equivalent to 1 kg of commercial-ready oysters. A functional unit is defined as the unit being studied so that all subsequent inputs and outputs are related to the functional unit (ISO 14044:2006). The target audiences of these LCA's within the Master's Project are academic researchers, regulators, oyster mariculturists, and other industry participants.

The purpose of analyzing these three LCAs is to identify and categorize the inputs that go into the oyster value chain and identify the outputs that are either helpful or harmful to the business case. Based on the results, impacts such as greenhouse gas emissions can be quantified and input options can be compared based on which has the least negative (or most positive) impacts. Overall, an LCA will help to reveal the benefits of oyster mariculture as well as the unintended outputs. Because of the numerous production inputs, stakeholders involved in the supply chain, and various methods of shell disposal and recycling, separate LCAs can be conducted to help identify and define impacts of these specific processes.

LCA: Birth to Harvest

The birth to harvest stage includes all of the inputs needed to raise and harvest a commercial-ready oyster. The transportation of that oyster to market and subsequent shell disposal are covered in the following two sections. All findingings are specific to the original author's LCA; application of findings to North Carolina is contained within the LCA Results Interpretation section of each LCA.

Life Cycle Inventory - Birth to Harvest

The inventory and analysis for this stage are drawn from an existing LCA by Tamburini et al. 2019. These researchers conducted a life cycle analysis of oyster mariculture in the Po Delta of Northern Italy, and compared the overall impact of raising local seed versus importing seed from France (approximately 1600 km). The system boundaries used in the LCA include scenario A, purchasing seed from France (Figure 1), and scenario B, local nursing and hatching (Figure 2). The inventory of main inputs includes resources, materials and fuel, chemicals, energy, transport from suppliers, emissions to air, and emissions to water (Table 2). The transport of raw materials to suppliers was outside the scope of this analysis.

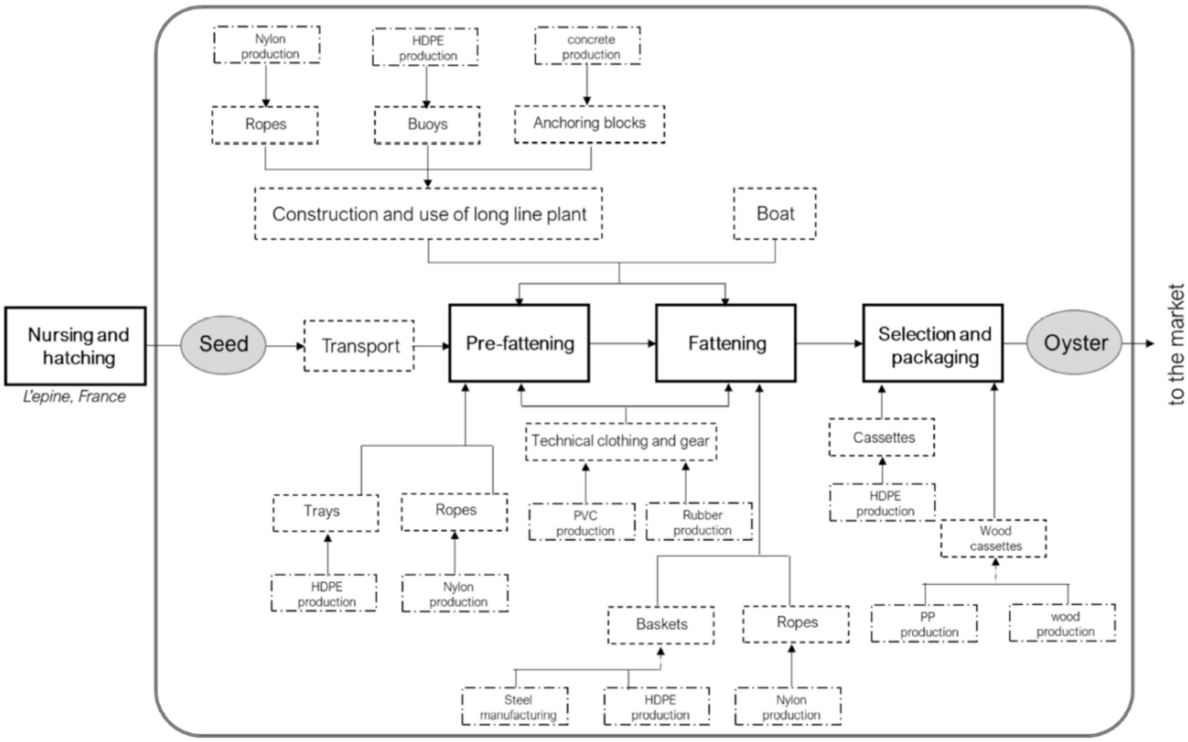

Figure 1: Scenario (A): Purchasing seed from France (Tamburini et al. 2019)

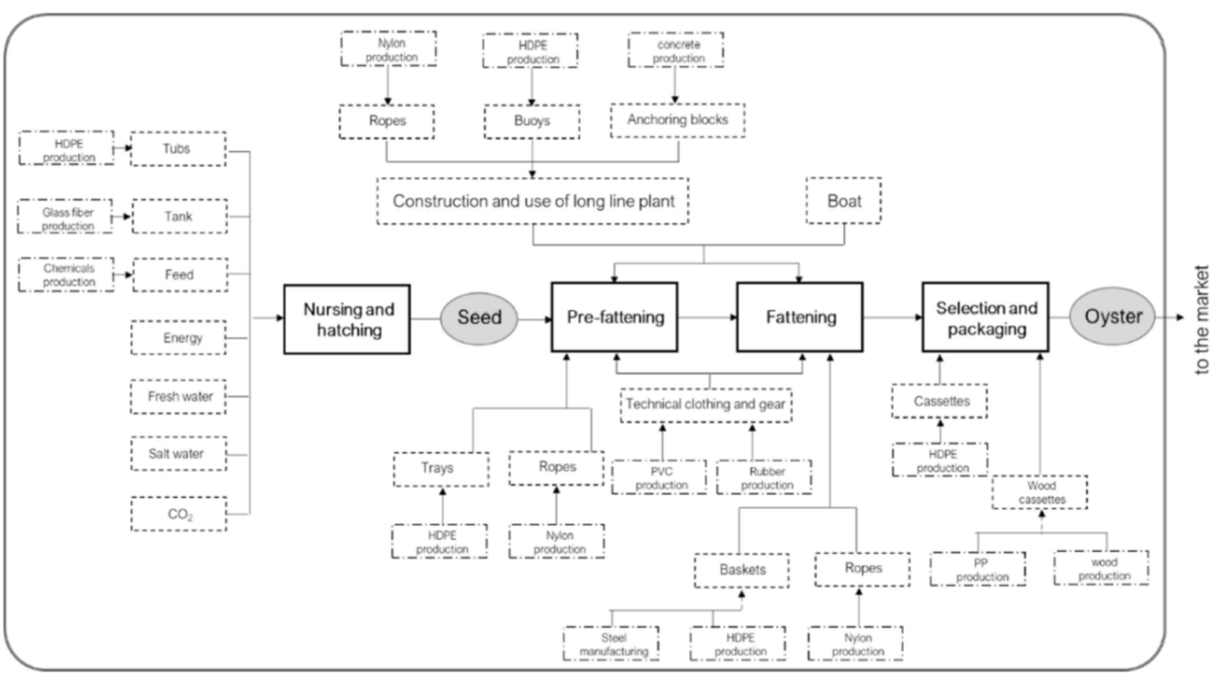

Figure 2: Scenario (B): Local nursing and hatching (Tamburini et al. 2019)

Table 2: Inventory of main inputs to the oyster birth to harvest process (Tamburini et al. 2019)

Inputs	Seed from France	Local Seed
Resources		
Sea use (m^2 $year^{-1}$)	-	120,000
Seawater (m^3)	-	160
Freshwater (m^3)	-	16
Materials and fuel		
High-density polyethylene (HDPE) (kg)	-	181.3
Polypropylene (PP) (kg)	-	16
Polyvinyl chloride (PVC) (kg)	-	1.24
Rubber (kg)	-	0.95
Glass fiber (kg)	-	2.7
Nylon (kg)	-	63
Concrete (kg)	-	144
Steel (kg)	-	0.6
Diesel for boat (l)	-	800
Wood (kg)	-	160
Chemicals		
Salt solution for feed (g)	-	40
Vitamins for feed (g)	-	6
CO_2 (L)	-	90
Energy		
Electrical energy (kWh)	34.2 *	1400
Vehicles		
Boat (no. of items)	-	0.033
Transport from suppliers to Goro		
Seed from L'Epine, France to Goro (tons km)	160	0
Tanks for seed production (tons km)	-	40.3
Prefattening trays (tons km)	-	2.23
Ropes (tons km)	-	0
PVC and rubber clothing (tons km)	-	0
Fattening baskets (tons km)	-	24.8
Cassettes for selection (tons km)	-	0.82
Wood cassettes for packaging (tons km)	-	0
Emissions to air		
Carbon dioxide (kg)	0.506	0.001
Nitrous oxide (kg)	0.0014	5.29×10^{-6}
Sulfur dioxide (kg)	0.0008	0.0006
Methane (kg)	3.26×10^{-6}	3.48×10^{-6}
Nonmethane volatile organic carbon (NMVOC) (kg)	0.0025	0.0025
Particulates <2.5 μ (kg)	0.00023	0.00023
Particulates >10 μ (kg)	4.78×10^{-5}	4.51×10^{-5}
Particulates >2.5 μ and <10 μ (kg)	6.86×10^{-5}	6.63×10^{-5}
Emissions to water		
Adsorbable organic halogen as Cl (AOX) (kg)		1.84×10^{-9}
Biochemical oxygen demand (BOD) (kg)		0.00062
Heat, waste (MJ)		6.79×10^{-5}
Nitrate (kg)		2.21×10^{-6}

* The contribution of energy to transport is related to the need for refrigeration.

Life Cycle Impact Assessment - Birth to Harvest

Birth to Harvest: Open-LCA version 1.8.0 software was used for the LCA, and the ECO Indicator 99 -H (hierarchic version; Blanc 2008) and ReCiPe midpoint version 1.12 (ReCiPe 2019) LCA databases were used for results interpretation. Total impact categories are listed in Table 3 (Tamburini et al. 2019).

Table 3: Impact categories considered, birth to harvest segment (Tamburini et al. 2019)

Impact Category	Unit
Human health: total	DALY *
Human health: climate change	DALY
Human health: carcinogenic	DALY
Human health: respiratory effects caused by chemical substances	DALY
Human health: ozone layer depletion	DALY
Ecosystem quality: total	PDF m^2 year **
Ecosystem quality: sea conversion	PDF m^2 year
Ecosystem quality: sea occupation	PDF m^2 year
Ecosystem quality: acidification and eutrophication	PDF m^2 year
Ecosystem quality: ecotoxicity	PDF m^2 year
Resources: total	MJ surplus energy ***
Resources: fossil fuels	MJ surplus energy
Resources: minerals	MJ surplus energy

Notes: * DALY = disability-adjusted life year, a measure of overall disease burden, expressed as the number of years lost due to ill health, disability, or early death. ** PDF m^2 year = The potentially disappeared fraction represents the fraction of species that disappear from 1 m^2 of earth surface over one year. *** MJ surplus energy = a measure of the amount of energy extracted or needed to extract a resource.

LCA Results Interpretation - Birth to Harvest

Scenarios A and B showed similar low environmental impact value across all categories. Three categories were considered: human health, ecosystem quality, and resources (Table 4). The largest impacts were during the fattening and pre-fattening steps (74% and 13% of total impacts, respectively), and were attributed to a barge’s diesel use: an oyster farm’s largest opportunity to decrease its overall impacts is to reduce the amount of diesel fuel used to run boats and/or barges. Baskets for fattening and wooden cassette packaging were the second and third most impactful items during these stages (Tamburini et al. 2019).

Table 4: Impact category results, birth to harvest segment (Tamburini et al. 2019)

Impact Category	Current (Seeds from France)	Alternative (Seeds In Situ)	Unit
Human health: total	0.0104	0.0104	DALY
Human health: climate change	0.0101	0.0101	DALY
Human health: carcinogenic	7.26×10^{-6}	7.26×10^{-6}	DALY
Human health: respiratory effects caused by chemical substances	2.31×10^{-6}	2.31×10^{-6}	DALY
Human health: ozone layer depletion	1.26×10^{-10}	1.26×10^{-10}	DALY
Ecosystem quality: total	0.0298	0.0298	PDF m^2 year
Ecosystem quality: sea conversion	0.0011	0.0011	PDF m^2 year
Ecosystem quality: sea occupation	0.0023	0.0023	PDF m^2 year
Ecosystem quality: acidification and eutrophication	0.0316	0.0315	PDF m^2 year
Ecosystem quality: ecotoxicity	0.0002	0.0002	PDF m^2 year
Resources: total	0.7544	0.7543	MJ surplus energy
Resources: fossil fuels	0.7467	0.7466	MJ surplus energy
Resources: minerals	0.0077	0.0077	MJ surplus energy

Scenario A, purchasing seed from France, did have higher impacts across “ecosystem quality: acidification and eutrophication” and “human health: climate change” than did scenario B, local seed production. Scenario A’s higher impact was primarily attributed to diesel fuel consumption and the energy needed for refrigerated trucks (Tamburini et al. 2019).

While North Carolina mariculturists do not purchase seed from France, they do mostly import seed from Virginia and Maryland. The diesel fuel and energy needed to deliver seed from these states will have a higher impact than if seed had been purchased from inside the state to a similar degree of seed imported from France to Italy. The use of diesel boats and refrigerated trucks to transport seed from France to Italy, a distance of approximately 1600km, is similar to the current transportation methods used to import seed from Virginia and Maryland to North Carolina, a range of approximately 400 to 650km.

Throughout our interviews, we asked where North Carolina oyster mariculturists purchased their seed from (in state versus out of state). Although there is some percentage of in-state purchasing, the majority of seed is imported from Virginia and Maryland, over approximately 400 km to 650 km (Oyster Farmer 3

2022, UMD Horn Point Hatchery 2022, Oyster Farmer 1 2022). The results from this LCA demonstrate the necessity for shorter supply chains for oyster farms to reduce environmental impacts on ecosystem quality and human health. Additionally, we asked about the types and quantities of materials and equipment farmers purchase. The LCA identifies particular practices and materials that have the highest impacts during the fattening and pre-fattening phases; these practices and materials should be prioritized when farmers seek to reduce impacts during the birth-to-harvest stage.

Distribution

The distribution stage includes all of the inputs needed to transport an oyster from a farm to a place where a customer will purchase the oyster. This stage could include multiple transportation legs (i.e. from farm to distributor to restaurant). Shell disposal is covered in the following section.

Life Cycle Inventory - Distribution

The inventory and analysis for this stage are drawn from an existing LCA by de Majewski et al. 2020. These researchers conducted a life cycle analysis comparing short and long food supply chains across 9 distribution scenarios (Table 5). The system boundaries for transportation include the manufacturing, use, and end of life of heavy goods, light goods, and passenger and city bus vehicles. Transportation eco-efficiency indicators were calculated for both retail to consumer (R2C) and product to retail (P2R). R2C includes consumers using personal cars or public transportation (buses), and P2R includes farmers, intermediaries, couriers, and retailers. The six eco-efficiency indicators all had relative environmental parameters applied across each transportation type (Table 6). The system boundaries also included a cradle-to-grave analysis of buildings that are used for commerce across distribution chains. These boundaries were conducted separately from the transportation analysis.

Table 5: Participation of producers, intermediaries and consumers in transportation activities in selected food supply chains (Majewski et al. 2020)

Chain	Producer Gate	Pink = Consumer Travel (R2C); Blue = Product Travel (P2R)				
			Short Chains			
a. Pick-your-own	Producer					Consumer
b. On-farm sales to consumers	Producer					Consumer
c. Internt sales--courier deliveries	Producer/Courier					Consumer
d. Direct deliveries to consumer	Producer					Consumer
e. Sales on farmers' markets	Producer				Farmers' Market	Consumer
f. Direct deliveries to retail	Producer				Retail Shop **	Consumer
			Long Chains			
g. On-farm sales to intermediaries	Producer	Agent	Wholesaler ***		Retail Shop **	Consumer
h. Sales to wholesale market	Producer		Wholesaler		Retail Shop **	Consumer
i. Sales to hypermarket chains	Producer	Producers Group **		Logistics Centre	Hypermarket Store	Consumer

"* The pink color in the table indicates a part of the physical distance in the distribution channel in which food is transported from the purchase (sales) by the consumer. Blue color indicates that the product travels from the farm gate to the sales point being transported by producers or intermediaries. ** Retail outlets including food stores, hotels and restaurants. *** Alternatively. Source: Malak-Rawlikowska et al. 2019"

Table 6: Environmental parameters for eco-efficiency assessments (Majewski et al. 2020)

	Functional Unit	Global Warming Potential	Acidification Potential	Eutrophication Potential	Ozone Depletion Potential	Photo-Chemical Ozone Creation Potential	Non-Hazardous Waste Disposed
		GWP kg CO_{2e}	AP kg SO_{2e}	EP kg PO_{4e}	ODP kg CFC-11_e	POCP kg C_2H_{4e}	NHWD kg
				Buildings and infrastructure			
Small store	unit/year	33,500	110	15	2.20×10^{-3}	6	900
Medium store	unit/year	246,100	650	98	1.35×10^{-2}	35	14,300
Large store	unit/year	1,028,000	3240	490	6.77×10^{-2}	173	71,600
Wholesales market	unit/year	3,196,600	15,460	2373	3.42×10^{-1}	884	452,200
Farmers' market	unit/year	111,800	590	85	1.08×10^{-2}	33	22,900
				Transportation vehicles			
Passenger car	unit/km	0.0358	1.98×10^{-4}	1.17×10^{-5}	2.11×10^{-9}	1.67×10^{-5}	0.0098
VAN	unit/km	0.0432	2.39×10^{-4}	1.38×10^{-5}	2.53×10^{-9}	2.02×10^{-5}	0.0094
Truck	unit/km	0.0369	1.95×10^{-4}	1.07×10^{-4}	3.09×10^{-9}	2.45×10^{-5}	0.0089
City bus	unit/km	0.0449	2.48×10^{-4}	1.40×10^{-4}	3.97×10^{-9}	3.06×10^{-5}	0.0110
				Energy sources			
Diesel	unit/l	3.240	4.67×10^{-3}	9.67×10^{-4}	5.50×10^{-7}	4.80×10^{-4}	0.019
Petrol 95E10	unit/l	2.800	6.00×10^{-3}	1.00×10^{-3}	5.00×10^{-7}	3.00×10^{-4}	0.020
Electricity, Europe	unit/kWh	0.386	2.17×10^{-3}	3.00×10^{-4}	4.17×10^{-8}	1.05×10^{-4}	0.014
Natural gas	unit/kWh	0.244	7.17×10^{-4}	4.83×10^{-5}	2.00×10^{-8}	4.83×10^{-5}	0.002

Life Cycle Impact Assessment - Distribution

The OneClick LCA calculation tool software was used for the LCA (Bionova 2020) and the ISO 14040 14044 LCA database was used for results interpretation. All food types included in this LCA were in the equivalent 1 kg functional unit; however, no specific analysis specifically included oysters (Majewski et al. 2020). Since the birth-to-harvest and end-of-life LCAs also used 1 kg functional units, results interpretation will not be affected.

LCA Results Interpretation - Distribution

Results indicate that the average value of the Food Miles indicator is over twice as long for short chains (1.25 km/kg) as it is for long chains (0.53 km/kg). Therefore, despite smaller vehicle weights used in short chains, the smaller quantities of food transported resulted in higher overall indicators compared to the longer miles and higher quantities of food transported in long chains.

Across the six eco indicators of global warming, acidification, eutrophication, ozone depletion, photo-chemical ozone creation, and non-hazardous waste disposed, the relative efficiency of the nine supply chains were weighted by the mean volume of sales in each respective chain (Figure 3). The share of transportation among the six eco-indicators for short and long chains demonstrates that long chains can perform better than short chains depending on transport distance and amount of goods sold (Table 7). Therefore, shortening a supply chain may not reduce environmental outputs if the quantity of food being transported is reduced and spread across multiple consumers.

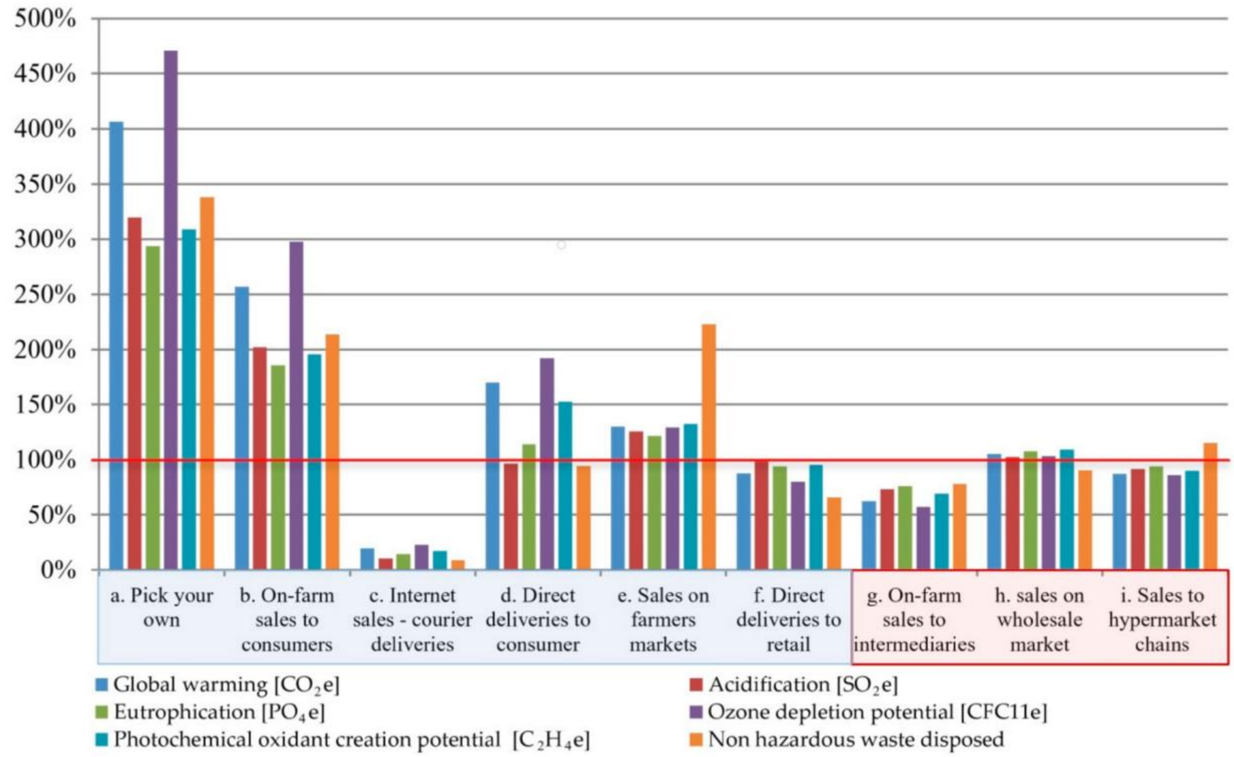

Figure 3: Relative eco-efficiency indicators (emissions per 1 kg of product) for supply chains related to weighted mean value = 100% (Majewski et al. 2020)

Table 7: Share of transport among eco-efficiency LCA indicators for short and long supply chains (Majewski et al. 2020)

	Global Warming	Acidification	Eutrophication	Ozone Depletion Potential	Photochemical Oxidant Creation Potential	Non-Hazardous Waste Disposed
	kg CO_2e	10^{-3} kg SO_2e	10^{-4} kg PO_4e	10^{-7} kg CFC11e	10^{-4} kg C_2H_4e	10^{-2} kg
SFSCs	79.2%	66.3%	65.7%	85.3%	71.4%	54.8%
LFSCs	53.6%	32.9%	35.9%	63.3%	42.6%	30.8%
Sample	62.9%	45.0%	46.7%	71.3%	53.1%	39.5%

Supply chains for oysters in North Carolina are primarily divided between direct deliveries to retail (scenario F, short chain), on-farm sales to intermediaries (scenario G, long chain), and sales on wholesale market (scenario H, long chain) (Oyster Farmer 1 2022, Sea Level NC 2022, Oyster Farmer 5 2022). These three distribution scenarios are relatively below, in-line with, or slightly above the average across all six eco-indicators, meaning they are preferable to the remaining six distribution scenarios. The only exception is scenario c, internet sales, which is the lowest scenario. This LCA did not specifically use oysters for this transportation mode, which would have included the production and disposal of dry ice to transport the oysters, increasing environmental impacts. Therefore, scenario c is not included as a viable transportation option for the industry at scale.

The results of this LCA suggest that the sustainability of the industry would not necessarily benefit from more farm-to-consumer sales (short chain), due to the lower volumes of oysters purchased and transported per consumer compared to the alternatives: scenario F (short chain), scenario G (long chain), and scenario H (long chain). Instead, local geographic groupings of farmers would need to partner with a single distributor to maximize the transport volume of finished oysters in order to ensure the lowest environmental impacts. Current state practices are the opposite; most individual farmers are selling small batches to individuals, other dealers, wholesalers, and retail (Oyster Farmer 2 2022).

End of Life

The end-of-life stage includes the disposal of oyster shells. This analysis compares the transportation and processing of shells into calcium carbonate, versus the transportation to a landfill and environmental effects of landfill deposition.

Life Cycle Inventory - End of Life

The inventory and analysis for this stage are drawn from an existing LCA by de Alvarenga et al. 2012. These researchers conducted a life cycle analysis of oyster deposition in a landfill compared to oyster processing to calcium carbonate (CaCo3). The system boundaries are scenario A: landfill and scenario B:

recycling (Figure 4). The inventory of main inputs includes seed production, oyster cultivation, packaging, shell processing, energy, and transportation. The infrastructure costs of facilities and impacts on marine environments were outside the scope of this analysis.

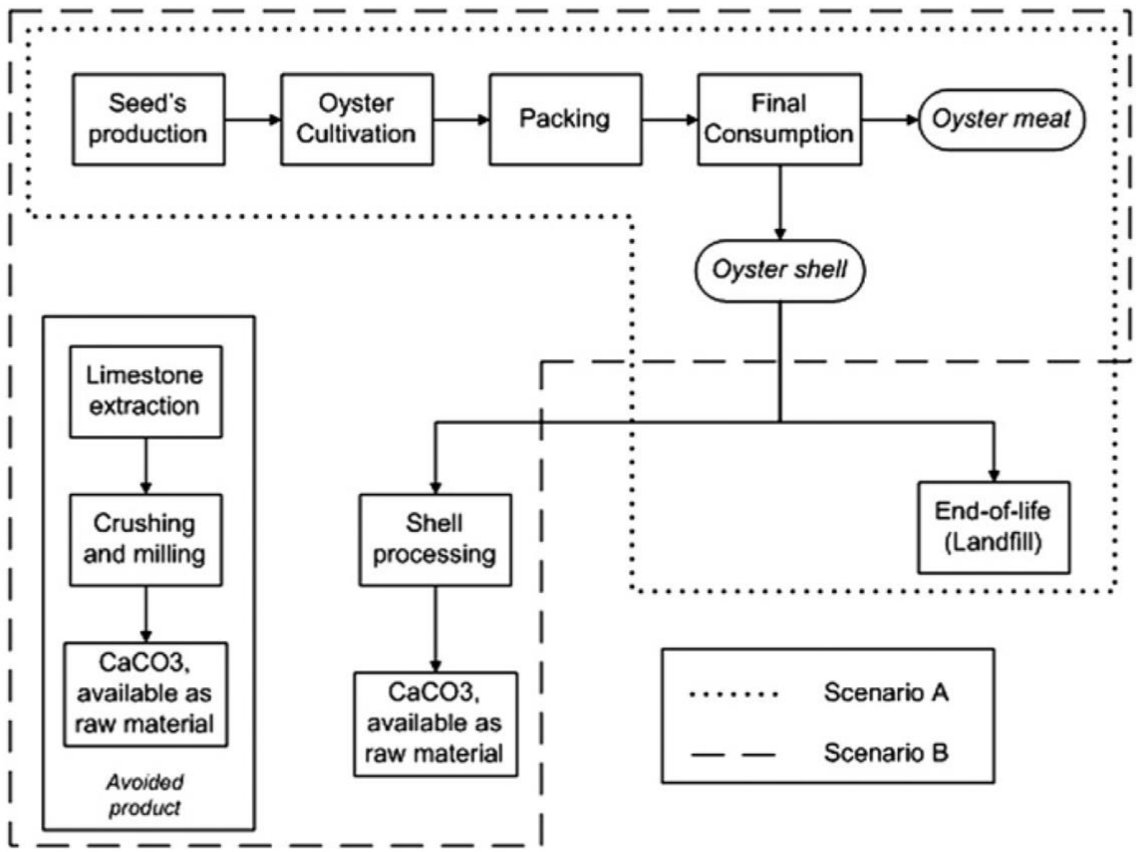

Figure 4: Oyster system boundaries for landfill versus recycling (Alvarenga, 2012)

Life Cycle Impact Assessment - End of Life

Simapro version 7.3 software was used for the LCA and the Eco Indicator 99 method was used for results interpretation (PRe Sustainability B.V.). Oyster production includes meat and shell production processes, but the environmental impacts of both were considered in a single "oyster production" process (Alvarenga et al. 2012).

LCA Results Interpretation - End of Life

This LCA utilizes a point system to weigh its results. Outputs are calculated on a millipoint (mpt) basis, where one thousand millipoints equals one point (pt). One point is the equivalent to the average person's annual share of environmental impacts in the United States. The total mpt values can be compared between scenario A: landfill and scenario B: recycling to measure the absolute difference in environmental impacts (Sustainable Minds 2016).

Scenario A: landfill deposition, yielded a value of 93.17 mPt. Of this total value, 55.10 mPt, or approximately 59%, came from the production, cultivation, packaging, and consumption phases, while 38.61 mPt, or approximately 41%, came from the end-of-life and transportation to end-of-life (restaurant to landfill) phases (Alvarenga et al. 2012).

Scenario B: oyster processing, yielded a value of 58.97 mPt. Identical processes for the production, cultivation, packaging, and consumption phases were used as in scenario A: landfill; scenario B: recycling also had a value of 55.10 mPt for these phases, representing approximately 93% of scenario B: recycling's total. The remaining 3.87 mPt, approximately 7% of the total value, was attributed to shell processing and transportation to the processing location (restaurant to processing facility). Because the shells were being used to create CaC03, the avoided cultivation and processing of limestone created a negative value of -1.32 mPt. During processing, 72% of impacts were from natural gas consumption and 28% were from electricity consumption. Overall, scenario B: recycling resulted in a reduction of 34.75 mPt, or a 37% reduction of the impact of scenario A: landfill (Alvarenga et al., 2012).

The largest improvement among environmental impact categories from scenario B: recycling compared to scenario A: landfill was in carcinogens, with a reduction of 21.54 mPt or 86% (Figure 5). This positive change "was primarily due to the elimination of the disposal of shell residues in a landfill because this option eliminates the process End-of-life from the Life Cycle Assessment" (Alvarenga et al. 2012). Other reductions in ecotoxicity, climate change, and respiratory inorganics were observed. 80% of the reduction in respiratory inorganics was due to the shorter distance to the processing facility than to the landfill (20 km difference); therefore, distance was further analyzed to determine the maximal range that would still produce environmental benefits. Overall, the LCA found that a distance of 323 km from the restaurant to the processing facility (scenario B: recycling) would maintain lower levels of carcinogens and ecotoxicity compared to scenario A: landfill, but levels of respiratory inorganics, climate change, land use, and fossil fuel would increase (Alvarenga et al. 2012). Any distance greater than this one would result in an environmental indifference between the two options of landfill versus recycling.

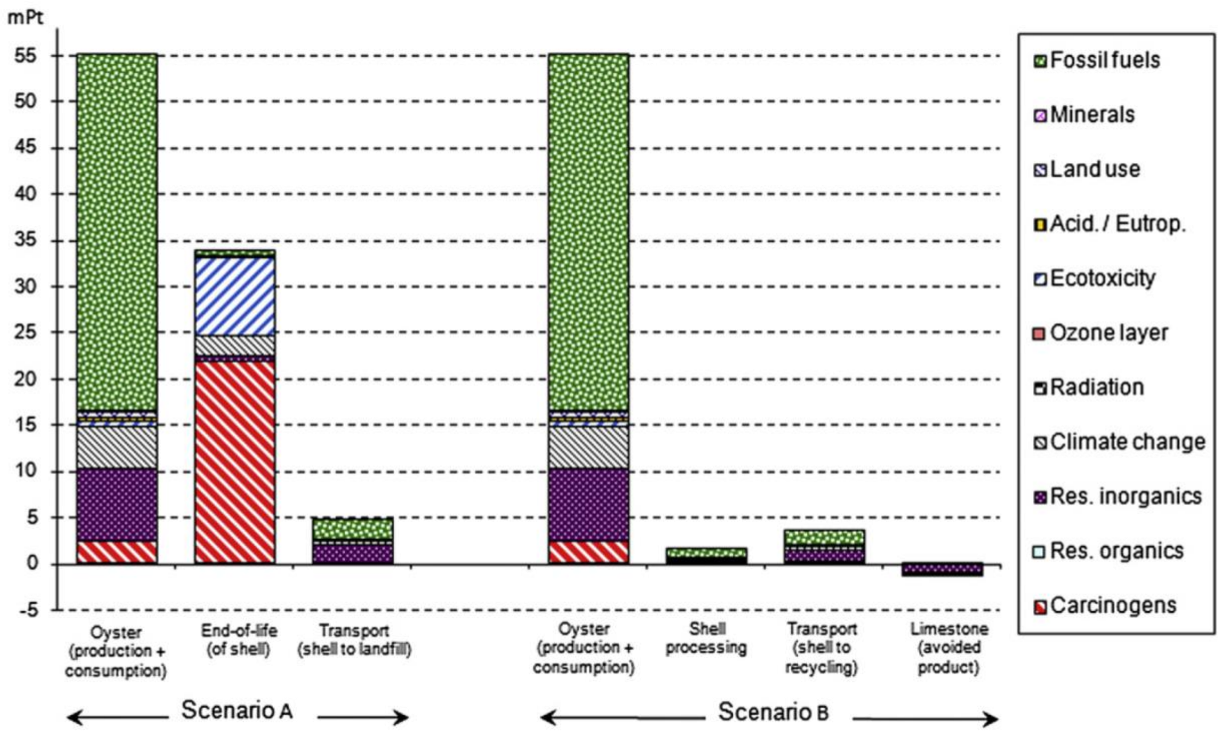

Figure 5: Scenario A: landfill versus Scenario B: recycling; LCA Results by Change in Macro Processes, (Alvarenga et al., 2012)

Throughout our interviews, we asked various stakeholders about their policies and processes for recycling their oyster shells. Responses ranged from throwing them into the estuary, to donating to coordinated recycling programs, to disposing of them into the landfill (Sea Level NC 2022, Oyster Farmer 1 2022, Oyster Farmer 2 2022). The results from this LCA demonstrate the benefits from oyster shell recycling compared to the landfill alternative. Similar to the results from the Birth to Harvest stage, the End of Life LCA puts emphasis on the positive impacts of shorter supply chains.

Discussion

The results from PESTEL, the toolkit, and the LCAs yielded recommendations directed at North Carolina state agencies, legislators, non-governmental organizations (NGOs), and oyster farmers. State agencies can take action to make the permitting process less burdensome for aspiring market entrants as well as expand financing options for new farmers. Legislators should analyze tying low-interest financing to business plans, funding commercial seed hatcheries, creating a blue carbon credit, and transitioning oyster farming regulatory authority from the Department of Marine Fisheries to the NC Department of Agriculture. NGOs should experiment with new ways to encourage industry entry, market access, and production expansion.

Recommendations for State Agencies

In North Carolina, the oyster mariculture regulatory framework and leasing protocols are well established. The permitting process generally takes about one year to get approved, after which the oyster farm can officially start operations. Advances in technology, such as better siting tools, have made the initial siting process more streamlined, but there are regulatory and social forces that interact and push back. Members of the local community may oppose the oyster farm location based on NIMBY attitudes. This friction can make the permitting process frustrating for aspiring oyster farmers, as it can extend the process by months or years. The NC Department of Marine Fisheries (DMF) should accelerate the SEA/SEZ pilot project to determine if this solution is actually viable, in order to reduce the permitting delay for new oyster farmers. Simultaneously, DMF should seek ways to extend their role in mitigating user conflicts from introducing aspiring oyster farmers to their neighbors, to educating the community at large about how to share space together while honoring everyone's disparate uses of public trust waters.

Looking across the economic and social portions of PESTEL, an interaction emerges between who is entering the oyster farming market and how they run their farm businesses. The two major groups of new entrants are established commercial fishers and first-time entrepreneurs. Fishers tend to prefer making cash purchases over using loans (Ferry Cove 2022), while brand-new entrepreneurs are more willing to use loans to fund business creation or advancement. The significance of this discrepancy relates to how state programs to support oyster mariculture are structured and prioritized: if most of the people entering oyster farming are commercial fishers, the initiative to create a formalized certificate of shellfish training might be more important, because the fishers are looking to build their skills more than to attain financing. If the opposite is true and most new oyster farmers do not have fishing backgrounds, financing options from the state might take precedence over skill development, because the start-up costs of establishing an oyster farm are significant. DMF should examine their lease application data to determine the relative interest from each audience and cater their recommendations and requests to the legislature accordingly.

Recommendations for Legislators

Data from states like Maryland and Arkansas suggest that state programs offering low-risk financing to aquaculturists to encourage them to enter the industry are most successful when paired with business planning advice and tools (Aquaculture Economist 2022). Pursuant to this finding, North Carolina state legislators should examine whether it makes the most sense to establish both a low-interest financing program and a formal business planning support position at the same time, instead of the recommendation from the most recent Oyster Blueprint that the low-interest financing be introduced first, with the business planning position coming several years later. It might even be the case that installing the business assistant first, and adding the low-interest financing option later, is optimal; analysis from the state would shed light on this question.

Regulations for oyster farmers may be better suited to fall under the NC Department of Agriculture (NCDA) instead of DMF, since oyster mariculture is more akin to terrestrial farming than finfish aquaculture. For one relevant example, there are technologies that can enable species to be selected for more growth cycles per year, similar to the crop harvest cycles. The NCDA also has more money and could create better-funded programs to support oyster farmers. Legislators should consider if this change of the agencies' roles is feasible, and if so, how best to responsibly and efficiently implement it.

While the environmental benefits of oyster mariculture are known, there are still inefficiencies in the way that the state incentivizes and rewards farmers for their environmental contributions. Terrestrial farms use chemical fertilizers that get washed into the water during storm events. These eutrophication events can cause major oyster die-offs, leaving farmers either to take a loss on production or to collect on their crop insurance–typically $0.30 per oyster (NC Department of Agriculture 2022). The funding of these agricultural practices directly harms mariculturists, insurance companies, and species that rely on clean bodies of water. Furthermore, there is no compensatory mechanism for the environmental benefits that oysters provide. North Carolina has an opportunity to create a type of blue carbon credit for mariculturists whose oysters are actively cleaning bodies of water. These types of incentives would make the first few years of farming less financially risky, while contributing to a national movement of creating a tradable instrument that financially benefits oyster farmers. Legislators should move this idea from the drawing board to execution and build a real credit trading program to test this approach, potentially using as templates the nutrient mitigation payment programs in Virginia and Maryland.

There are additional areas where the environmental impacts from oyster mariculture can be improved. Funding for in-state commercial hatcheries and nurseries would eliminate the need to import seed from out of state. This development would confer the additional benefits of bolstering local economies that operate these nurseries and ensuring a reliable seed source for local farmers. State-wide shell recycling programs, or resources for local programs, would also have tremendous environmental benefits. The siting locations for both nurseries and recycling centers would need to be strategically placed to reduce the amount of vehicle miles driven to reach these sites. Any time oysters are shipped, alive or dead, the shipping load should be maximized to reduce environmental impacts; thus, incentivizing local markets over mass-distribution lines may not be the most overall environmentally friendly option.

Recommendations for NGOs

Other actors beyond the state could also benefit from insights on market structure. For example, NC commercial fishers are not very interested in working together to solve the market access problem that small growers face, but new entrepreneurs–often skewing younger–are more interested in this option. Young people also demonstrate more savvy with social media, a crucial tool for connecting to customers via Direct-to-Consumer (DTC) and eCommerce revenue streams. Entities like NC Sea Grant and the North Carolina Coastal Federation, who are finding and filling gaps in the industry to support growers and expand production, might focus more on building the capacity of oyster growers to collaborate on market access if they knew that most new oyster farmers were open to the idea. These organizations should put forth a similar effort to DMF to ascertain the profiles of those entering the industry in order to design programs that are most suitable to their clients' needs.

Conclusion

The sophisticated and highly engaged constellation of stakeholders that is moving oyster mariculture forward in North Carolina is well positioned to consider and apply the findings of this project. The primary contribution of this research is to illustrate areas where the implementation of already discussed proposals–like low-interest financing, Shellfish Enterprise Zones, or business planning assistance–could be altered and improved in order to support the business case for oyster mariculture in North Carolina.

The current legal framework for oyster mariculture in North Carolina both helps and hinders aspiring farmers. The laws are set up to encourage small farmers to enter the industry, but then can discourage would-be farmers through a lengthy permit approval process that can be scuttled by any property owner adjacent to the site who is not in favor of the farm. The state's political landscape is receptive to the concerns of local farmers, but laws are often passed that are physically and financially encumbering to farmers, or would be helpful to farmers but then simply go unfunded by the state.

Oyster mariculture regulation is housed in North Carolina's Department of Marine Fisheries and not the better-funded Department of Agriculture, but the process of growing and harvesting oysters is more akin to terrestrial farming than finfish aquaculture. Therefore, an argument could be made that there is a mismatch with respect to the laws and available financial support for oyster mariculture. This mismatch has the potential to cause underfunded oyster mariculturists to lack the capital to adopt new technology, incorporate more expensive reusable materials, or recover from storm events. Further, it leaves economic gaps in the industry that other states are currently filling, contributing to reduced environmental benefits and economic returns within North Carolina.

The clearest hindrance to the oyster industry in North Carolina is that there is not enough commercial hatchery capacity to provide seed for the farmers in the state; the majority of the seed purchased is from out of state. Government funding of commercial nurseries and hatcheries would provide multiple benefits. Seed from in state would be less expensive than imported seed, helping farmers save money; out-of-state seed requires disease testing, an import permit, and DMF approval, and does not survive as well as NC-bred family lines. Further, shorter seed supply chains would reduce the negative environmental impacts of long transportation chains from out of state.

Targeted programs to facilitate shell recycling would help close the loop of oyster production in North Carolina. Policy and economic support for local, in-state shell processing facilities could optimize the environmental benefits of end-of-life use for oyster shells. State-sponsored oyster shell recycling programs for estuary deposit could also provide environmental benefits compared to landfill deposit, depending on the amount of transportation required.

Areas for Further Research

There are several ideas that the PESTEL analysis touched upon but did not cover in depth, which would benefit from further exploration in future research. The first such topic is opening a commercial hatchery in North Carolina. What would be required to start such a facility? Who might be the best actor to do so, and what kinds of support would they need from other players in the space? Secondly, there is currently a paucity of available data to support the proposed programs to pay oyster farmers for salutary impacts like nutrient reduction, carbon sequestration, and/or habitat provision. Payments for Ecosystem Service (PES) programs rely on clear, robust data to substantiate their payouts, and these programs will not come into existence in NC until stakeholders possess that data. Future research could test these mechanisms quantitatively and start generating this data. The third topic from PESTEL that merits more scrutiny is the SEA initiative. DMF is prioritizing avoiding user conflicts, but oyster farmers are concerned about proximity to markets: it would be valuable to investigate whether siting processing or other related infrastructure in the area between western Pamlico County and the big oyster markets in the state would help bridge these two different concerns. Fourth and finally, many growers complained that a resource management agency like the Department of Marine Fisheries should not be responsible for oyster farms, and instead the state Department of Agriculture should take on this role. It would be illuminating to analyze whether and how it would be legally possible to make this switch, and what changes would result from the new management arrangement.

Further areas of research with life cycle analysis could consider local data inputs from participants in the North Carolina Oyster Trail. Examples include mandated equipment such as siting poles, common equipment such as floating cages and nets, new technology such as Pearlception, and specific aquatic and terrestrial transportation modes and fuels used by farmers and distributors. An additional area of interest is an end-of-life life cycle analysis demonstrating the environmental benefits (or costs) of shell processing facilities within the state compared to landfill or estuary alternatives.

Appendix A (Interview Guide)

Name of Interviewee(s):

Title(s):

Contact Info:

Role in Industry

- Please tell me about your job. What is your role in your organization? How long have you been in this role?

Permitting

- What is your impression of the aquaculture permitting process? Does your office help farmers navigate this process?
- Do you know of, or have you taken part in, any state-level or local processes to adjust the permitting process for lease applicants?
- Is there anything you would like to change in the permitting process? (If so, how?)

Regulations

- How do aspiring aquaculturists get up to speed on the various laws that apply to the industry?
- What is your impression of the relationship between the various government agencies with jurisdiction over aquaculture?
- Do you know of any coordinating entities between the various government agencies that handle aquaculture?

Siting

- What resources exist to help new shellfish growers navigate the process of siting and figure out how is already using the shoreline, and for what purposes?

Farm Size

- Do you think smallholder farmers have the ability to get established and thrive in the NC aquaculture industry? Why or why not?
- How do the obstacles faced by smallholder farmers in creating a new business differ from those of the bigger players?
- Based on your experience with aquaculture, what is the smallest feasible size aquafarm for someone to make a living solely off of aquaculture?
- Are there existing small-scale, “family owned/run” farms or are the aquaculture farms mostly large-scale? Are there any that you could refer to us to interview?

Seed

- What kind of financial investment is required to start oyster farming for a living? (seed, siting, etc.)

Industry Dynamics

- Have you seen an increase in new entrants into the oyster farming industry?

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