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Exploring Nationwide Oyster Aquaculture Data: An Index to Compare Regulatory, Production, and Economic Attributes of Oyster Aquaculture Among U.S. States and Regions

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Abstract: Wild oyster reefs have been harvested for centuries and continue to face anthropogenic pressures, including climate change, pollution, and habitat reduction. Oyster aquaculture has grown to supplement depleted wild stocks and strengthen local economies, but development has not occurred at the same rate across all regions. Across the United States, states have a variety of political and cultural influences that impact oyster aquaculture policy, constraining the ability to make direct comparisons among locations that could enhance aquaculture expansion in slower-to-develop states and regions. This research developed a four-part index to compare regulatory, production, and economic attributes of oyster aquaculture among 23 coastal states. The final index score—a summation of the four individual index components—provides a broad integrated view of oyster aquaculture across the U.S. The results indicate that coastal states in the U.S. Mid-Atlantic and New England regions have the greatest number of resource and policy attributes in place to support oyster aquaculture, whereas coastal states in the Gulf of Mexico and Western Pacific region have relatively less in the way of aquaculture-supporting structures. As the oyster aquaculture industry continues to grow in the U.S., results from this study can help organizations involved in oyster aquaculture to make informed decisions to expand permitting, leasing, and production systems, following the model from states who have been active in oyster aquaculture for decades. Mindful and cautious improvements can facilitate sustainable sources of seafood and stable income generation for coastal communities while reducing pressures on wild stocks.

Keywords: *C. gigas*; *C. virginica*; coastal planning; marine spatial planning; bivalve; non-feed aquaculture

Key Contribution: This research developed a method to compare aspects of oyster aquaculture across U.S. coastal states and found that the Mid-Atlantic and New England regions are top producers with many regulatory attributes that could support sustainable oyster aquaculture nationwide. The industry's strength is hypothesized to stem from long-term reliance, cultural importance, and collaborative strength between multiple government agencies.

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1. Introduction

Oyster reefs in the U.S. and throughout much of the world continue to experience losses due to anthropogenic pressures such as habitat loss, overharvesting, and environmental degradation [1]. Estimates of worldwide oyster reef loss are as high as 85% in some locations [2]. The Chesapeake Bay, once the largest American fishery in the late 1800s, has experienced declines as high as 99.7% in oyster abundance [1]. In addition to the loss of wild oysters impacting coastal communities, there has also been a loss of ecosystem services provided by the reefs. Beneficial services such as nutrient management [3–5], support of fish species via structure and habitat [6,7], and the dissipation of storm energy are all reduced with the loss of oyster reef systems [7].

Bivalve restoration projects [8] and governmental aquaculture initiatives [8] have gained momentum in recent years. Bivalves can act both as restorative to water quality and ecosystem habitats, as well as serve commercial and food security objectives. Within aquaculture, bivalves and other "non-feed" species (i.e., algae, seaweed) have some advantages over other aquatic species cultivation, such as finfish or shrimp, by reducing the need for fishmeal or other external inputs [9,10]. Oyster production and transplantation have been widely applied in restoration efforts due to their broad ecological benefits, including enhancing the water quality of tidal creeks [11], mitigating shrimp farm effluent [12], and providing a variety of ecosystem services [13]. The beneficial nature of oyster cultivation, both to society and ecosystems, has led to industry growth across all major coasts of the United States, using a variety of different techniques (on-bottom, hanging, rafts, etc.) adapted to local regions, and using a network of hatcheries and laboratories to provide seed and technical needs across the industry. Aquaculture globally has grown rapidly and accounts for over 50% of the seafood generated worldwide today [14]. In the United States, aquaculture accounts for 7% of total weight produced in the United States, with roughly 24% of the value [15] driven primarily by bivalves. Sales of molluscan seafood from aquaculture have consistently increased more rapidly than any other aquaculture category in the United States (Figure 1).

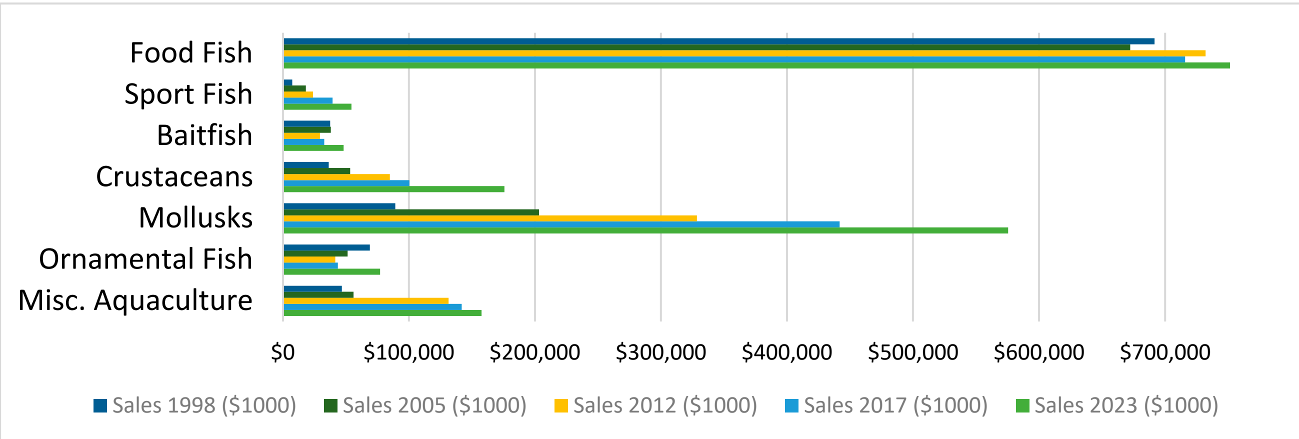

Figure 1. Aquaculture sector sales in the United States 1998–2018 [16–18].

Five species of oysters are grown commercially in the United States. Two species—the eastern oyster (*Crassostrea virginica*) and the Olympia oyster (*Ostrea conchaphila*)—are native to U.S. waters. The Pacific oyster (*Crassostrea gigas*), Kumamoto oyster (*Crassostrea sikamea*), and European flat oyster (*Ostrea edulis*) have been introduced from Asia and Europe [19,20]. Among these, *C. virginica* and *C. gigas* dominate the commercial market [18,21]. According to the most recent data in the 2023 United States Department of Agriculture (USDA) Census of Aquaculture, the eastern oyster leads in production, with 707 farms and the highest sales value at approximately USD 152 million, accounting for about 45% of total sales. The ability of *C. virginica* to survive a wide range of coastal and estuary conditions has enabled the species to be harvested via the wild and cultivated populations that occur throughout the Gulf of Mexico and the entire U.S. Atlantic Coast. The Pacific oyster follows closely with sales valued at USD 150 million (roughly 44% of total sales), though it is cultivated on significantly fewer farms (175) [18]. The remaining 10% of sales are attributed to the other species, with a smaller role in the industry.

Although the growth of oyster aquaculture has been apparent through the past few decades, few studies have compared oyster aquaculture on a state-by-state basis. Research within the field is typically undertaken as a case study for one state or region, or to address a specific concern. The present research fills a gap in information by compiling quantitative and qualitative data within a single, robust, and multi-faceted index. Indices have been used to measure other complex ideas such as global food security [22], agricultural sustainability [23,24], and fishery health [25]. The application of an index-based approach on oyster aquaculture enables the use of different types of quantitative and qualitative features and indicators to provide a broad comparison over unique states. The improved understanding of data collection used in this analysis and the identification of trends can be used to strengthen decision making within oyster aquaculture.

2. Methods

2.1. Study Area

The geographic extent of this study was all 23 U.S. coastal states where marine bivalve production takes place, and commercial data are available through the USDA Census of Aquaculture [16–18]. This study treats states individually, even though some states may have multiple agencies involved in permitting, regulations, and data management. For Maine and Connecticut, where municipalities issue permits in addition to state entities [26], and for Delaware, where shellfish programs are reported for both Delaware and Inland Bays [26], values were summed to generate one score per state.

2.2. Index Development

This research developed a four-part index to compare regulatory, production, and economic attributes of oyster aquaculture among U.S. states. Two parts of the index, the Aquaculture Policy Enabling Score [27] and the Shellfish Map Viewer GIS Score [28], were derived from published studies used to compare different aspects of oyster aquaculture, including policies designed to benefit the overall aquaculture industry, and a comparison of publicly available GIS data used in siting across states. The two additional portions of the index (Oyster Production Quantitative Score, Oyster-Specific Regulatory Environment Score) were developed within this project by utilizing existing quantitative and qualitative data and through web search. The Oyster Production Quantitative Score is designed to process quantitative metrics of the oyster aquaculture industry, such as oyster sales figures and the number of leaseholders per state. The Oyster-Specific Regulatory Environment Score uses binary attributes to review policies considered beneficial for oyster aquaculture development within a state, such as state training or lease transferability within each state. The Final Oyster Aquaculture Score—a summation of the four individual index components—was developed to provide a broad integrated view of oyster aquaculture across the U.S. (Figure 2).

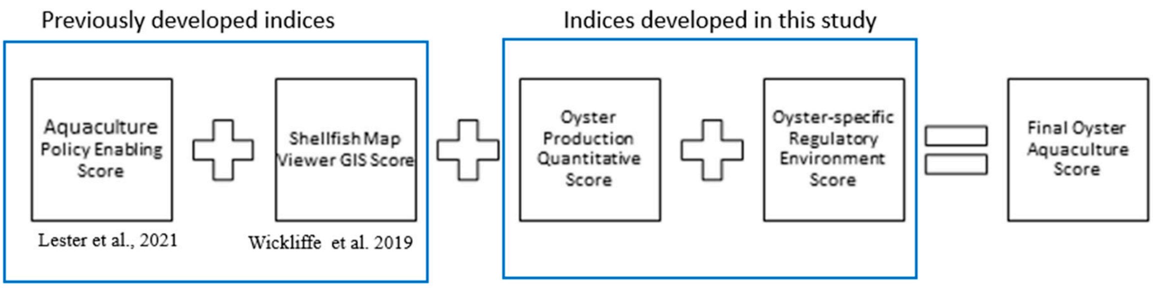

Figure 2. Composition of the Final Oyster Aquaculture Score. The Final Oyster Aquaculture Score is the summation of four individual index scores, each providing different types of information regarding oyster aquaculture in the U.S. [27,28].

2.3. Existing Indices

Two existing indices were used as part of this study. The first is the Aquaculture Policy Enabling Score [27], which was derived from a comprehensive evaluation of 16 aquaculture and mariculture policy attributes among 23 coastal U.S. states. The Aquaculture Policy Enabling Score focuses on aquaculture broadly, including attributes that affect finfish, shellfish, and other forms of aquaculture. Policy attributes include aquaculture development acts, government-provided (or endorsed) best management practices (BMPs), regulatory guidance, and other enabling policies that assist aquaculture industry development within a state. Possible points within the Aquaculture Policy Enabling Score included 0, 0.5, or 1.0 for each policy attribute within each state and were summed (max score of 8) to obtain the Aquaculture Enabling Policy Score.

The other existing index used is the Shellfish Map Viewer GIS Score [28], which was developed by examining map layers across seven categories, such as oceanographic, infrastructure, or geomorphological data. Of the 23 coastal states, 16 states had online shellfish map viewers available during the study [28]. The availability of geographic data facilitates decision making and siting of aquaculture in coastal waters. These publicly accessible data also provide essential information to shellfish farmers (e.g., improved spatial awareness of other users) to use in consultations with state resource managers [29,30]. The number of data layers was summed across all categories to obtain each state's Oyster Shellfish GIS Score, with values ranging from 3 to 27. States without shellfish map viewers had no data available and received a 0 for the Shellfish Map Viewer GIS Score [28].

2.4. Indices Created for This Study

Two reports were used in developing the Oyster Production Quantitative Score, which characterized cultivated oyster aquaculture in the U.S. The first source was the USDA Census of Aquaculture, a voluntary self-reported survey conducted every five years. It provides detailed species- and state-specific data on production methods, types of production, and sales. Some information, such as sales or lease acreages, may be withheld due to privacy concerns when too few producers are in the same state. This research uses data from every year in which the USDA Census of Aquaculture collected information regarding oyster sale value and the number of oyster farms [16–18] (Table 1). Some data within the USDA Census of Aquaculture are not published due to privacy concerns, and other metrics such as individual lease sizes are not publicly available.

Table 1. The Oyster Production Quantitative Score. Metrics denoted with [1] are from the USDA Census of Aquaculture [16–18]. Metrics denoted with [2] are from the "State by State Summary of Shellfish Aquaculture Leasing/Permitting Requirement 2021" [26]. The point system is designed to use multiple quantified metrics to understand states with active and growing oyster aquaculture industries. The total possible score is 22.

Metric	Point	Maximum Points
Reported Sales in 2012, 2017, and 2023 [1]	One point for each data entry (2012, 2017, 2023). One point if within the top five highest reported sales.	6
Change in sales from 2012, 2017, and 2023 [1]	One point for increase when positive from previous entry.	2
Reported number of Farms in 2012, 2017, and 2023 [1]	One point for each data entry (2012, 2017, 2023). One point if within the five top states with highest numbers of farms.	6
Change in number of farms from 2012, 2017, and 2023 [1]	One point for increase when positive from previous entry.	2
Average Yearly Shellfish Lease Applications [2]	One point for active shellfish applications.	1
Total Shellfish leases [2]	One point for data entry. One point if total in top five.	2
Acreage of shellfish aquaculture (#) [2]	One point for data entry. One point if in top five.	2
Leaseholders (#) [2]	One point for data entry.	1

The second data source for the Oyster Production Quantitative Score was the "State-by-State Summary of Shellfish Aquaculture Leasing/Permitting Requirements" [26]. This report provides an overview of permitting and leasing programs in U.S. state waters, including data such as permit requirements, lease terms and conditions, natural resource permits, and other metrics that vary by state. This research used four data fields from the report: average yearly leases, total number of shellfish leases, total acreage of shellfish aquaculture, and the number of leaseholders. A total of 22 points were possible from the Oyster Production Quantitative Score, from either 1 or 0 based upon the scoring criteria described.

The Oyster-Specific Regulatory Environment, the final component of the index, was developed to evaluate attributes related specifically to oyster aquaculture. Methods follow those of [27], where states either have or do not have specific attributes (Table 2). Two data sources were used to develop this index: a Google search and the State-by-State Summary of Shellfish Aquaculture Leasing/Permitting Requirements, also used in the Oyster Quantitative Score [26]. First, a Google search was used to determine whether oyster gardening (non-commercial aquaculture of oysters typically for restoration [31]) or pre-zoned aquaculture was utilized within each state. Google searches were conducted using the keywords "oyster gardening", "preplanned aquaculture", "aquaculture parks", "preapproved aquaculture lease", and "oysters", along with the names of the individual states and natural resource management agencies. Google searches targeting each state's natural resource management agency website and industry organizational websites (Oyster South, East Coast Shellfish Growers Association, West Coast Shellfish Grower's Association) were also searched for the same keywords. In all cases, the first twenty links were examined. All other attributes were retrieved from the "State-by-State Summary of Shellfish Aquaculture Leasing/Permitting Requirements (2021) [26]". Each of the 12 attributes within the Oyster-Specific Regulatory Environment Score is either 1.0 if a state has that attribute or 0 if that state does not. The maximum score is 12.

Table 2. Attributes within the Oyster-Specific Regulatory Environment Score. Metrics denoted with [1] were found using a Google search. Metrics denoted with [2] are from the "State by State Summary of Shellfish Aquaculture Leasing/Permitting Requirement 2021" [26]. All qualitative metrics use a "Yes/No, Presence/Absence" for scoring. This study views the presence of these characteristics as generally positive for the industry if thoughtfully managed and effective and awards a point for all 12 attributes. Each attribute is worth 1 point if it is present in the state and 0 if the attribute is not present.

Attribute	Rationale/Definition
Oyster Gardening (Personal Consumption) [1]	Oyster gardening is the practice of coastal landowners growing oysters, typically on piers or docks, for personal consumption. This represents an acceptance of aquaculture from the state's perspective.
Aquaculture Parks [1]	Areas predetermined to be leasable for aquaculture, reducing cost and time associated with permitting.
State Training or Certification (not HACCP for the DFA) [2]	The state provides mandatory or voluntary training for growers.
Insurance Requirement [2]	Mandatory insurance to keep an active lease.
Lease Transferability [2]	The ability of a grower to sell, sublease, or other alternatives to complete farm removal.
"Use it or lose it" Active Use Criteria [2]	Farms must meet a productivity requirement to continue to hold the lease, usually providing some flexibility for the first years or through unforeseen environmental circumstances.
Residency Requirement [2]	The leaseholder must be a resident of the state they are leasing from. Residency requirements may prevent investment from outside of the state. However, residency requirements may ensure that local economies are the focus of aquaculture endeavors, and there is a greater focus on the community and other stakeholders who share the ecosystem.
Joint Permit Application (JPA) [2]	States have worked with federal partners to create documentation that serves both entities, typically with the USACE.
Applicant Guide [2]	Additional guidance to permitting is provided online or through a .pdf that anyone can easily access at any time.
Process Flow Chart [2]	A visual, graphic, or flow chart helps applicants understand other organizations' timelines and hierarchal requirements.
Operational Plan Requirement [2]	An operational plan is required to be issued a lease from the state's natural resource agency.
Financial Plan Requirement [2]	A financial plan is required to be issued a lease from the state's natural resource agency.

2.5. Data Synthesis

Each component of the four-part index was normalized from 0 to 1 and then summed to obtain the Final Oyster Aquaculture Score, ranging from 0 to 4 (Table 3). Each component was given equal weight, despite some categories having more factors than others, in order to (1) prevent one category with many variables from being weighted too heavily, (2) ensure all categories represent data that are required for successful oyster aquaculture, and (3) balance the work used in this research with research from other publications with varying methodological styles and rationales. Each index component represents aspects necessary for a successful oyster aquaculture industry (i.e., supportive aquaculture policy, publicly available GIS and spatial tools, active production, and regulations specifically supporting the cultivation of oysters). Each of the states was scored individually using all four index components and grouped regionally using the National Marine Fisheries Service (NMFS) regional offices. Regional groupings can find similarities and norms among states, which may have similar scores based on similar environments, economic dependence, and attitudes toward oyster aquaculture.

Table 3. Final index composition and values. Each index component was normalized from 0 to 1, for a possible total of 1.0 in each index component. Then, each of the four scores were summed to equal a total possible score of 4.

Index Component and Source	Rationale	Calculation	Contribution to Final Score
"Policy Enabling Score" [27]	Used to understand the overall acceptance and popularity of aquaculture within a state.	Total "Aquaculture Enabling Policy Score" (0–8)	25%
"Shellfish Map Viewer" GIS Score [28]	State infrastructure and data management are required for decision making and industry longevity.	Total "Number of Data Layers per Category" (0–27)	25%
Oyster Production Quantitative Score	A measure of oyster aquaculture output, such as the number of farms and value of sales.	Point system described in Table 2 (0–22)	25%
Oyster-Specific Regulatory Environment Score	A focused approach to understanding regulations directly aimed at oyster aquaculture production.	Number of oyster-specific attributes that states engage in (0–12)	25%

3. Results

3.1. Results of Oyster Production Quantitative Score

Across the U.S., the number of oyster farms increased by 86.34% from 483 farms in 2013 to 701 farms in 2018. However, growth slowed in 2023, with the total remaining at 701 farms, reflecting a 28.39% growth rate over the five-year period. Meanwhile, oyster sales experienced a 58.23% surge, rising from USD 180.15 million in 2013 to USD 284.94 million in 2018. By 2023, sales reached USD 326.98 million, though the pace of growth tapered to 14.77% over the five-year span. In 2023, the states with the highest recorded number of farms were Massachusetts (191), Washington (116), and Virginia (87), and the lowest recorded number of farms were in South Carolina (6), Hawaii (5), and Mississippi (3). Also, in 2023, the lowest sales figures were North Carolina (USD 1,387,000), Alabama (USD 932,000), and Delaware (USD 335,000). Seven states recorded sales greater than USD 10,000,000 for 2023: three from the Atlantic (Connecticut, Virginia, and Massachusetts), two from the Pacific (Washington and California), and two from the Gulf of Mexico (Georgia and Louisiana).

Respondents were allowed to make any entry they desired into the State-by-State Summary of Shellfish Aquaculture Leasing/Permitting Requirements (NOAA Fisheries, 2021) survey, resulting in substantial variation in data entries that were more complicated than others, including estimates and ranges of values. North Carolina (~80), Florida (~75), and Virginia (~60) had consistently high numbers of shellfish lease applications. The states with the most leased acres for bivalve aquaculture were Louisiana (403,943 acres), Virginia (136,136 acres), and New Jersey (34,450 acres). Virginia (1600), Florida (418), and Massachusetts (409) had the most reported leaseholders within the U.S.

Using the 22-point methodology for the Oyster Production Quantitative Score (Table 1), the highest-performing states were Massachusetts (0.91), Virginia (0.77), and Washington (0.77) (Table 4). The size of the industry in these states benefitted from more robust data due to the number of respondents and well-established organizations that were more consistent across time. States with lower scores included Mississippi (0.05), Georgia (0.09), and Texas (0.18), which have traditionally relied more on wild-caught oysters, and resulted in more gaps in the data using the USDA Census of Aquaculture.

Table 4. Heatmap of each index component and Final Oyster Aquaculture Score. This table is derived from each state's individual index score in Table 3. Green colors indicate higher scores, while red colors indicate lower scores. Heatmaps are colored by column.

Region	State	Policy Enabling Score (Lester)	Shellfish Map Viewer Score (Wickliffe)	Oyster Production Quantitative Score	Oyster-Specific Regulatory Environment	Total
North Pacific	AK	0.81	0.00	0.45	0.58	1.85
Pacific	CA	0.69	0.00	0.64	0.42	1.74
	OR	0.44	0.00	0.50	0.58	1.52
	WA	0.81	0.78	0.77	0.67	3.03
Western Pacific	HI	0.56	0.00	0.23	0.17	0.96
New England	CT	0.63	1.00	0.59	0.58	2.80
	MA	0.88	0.81	0.91	0.50	3.10
	ME	0.44	0.52	0.55	0.58	2.08
	NH	0.00	0.33	0.41	0.33	1.07
	RI	0.75	0.52	0.50	0.75	2.52
Mid-Atlantic	DE	0.81	0.11	0.23	0.58	1.73
	MD	0.88	0.74	0.36	0.67	2.65
	NJ	1.00	0.96	0.50	0.50	2.96
	NY	0.50	0.26	0.50	0.83	2.09
	VA	0.50	0.74	0.77	0.75	2.76
South Atlantic	FL	1.00	0.00	0.50	0.75	2.25
	GA	0.56	0.52	0.09	0.58	1.75
	NC	0.69	0.78	0.64	0.58	2.68
	SC	0.44	0.15	0.36	0.58	1.53
Gulf of Mexico	AL	0.31	0.81	0.45	0.58	2.16
	FL	1.00	0.00	0.50	0.75	2.25
	LA	0.56	0.00	0.64	0.33	1.53
	TX	0.19	0.30	0.18	0.33	1.00
	MS	0.44	0.00	0.05	0.67	1.15

3.2. Results of Oyster-Specific Regulatory Score

Among the attributes listed within the Oyster Specific Regulatory Environment Score, the most common attributes within states are the operational plan requirement (91%), applicant guides (87%), lease transferability (87%), and active use criteria (78%) (Table 5). The attributes found in the fewest states include insurance requirements (22%), financial plan requirements (30%), and residency requirement (35%). Of the twelve listed attributes, the states with the highest number of attributes listed include New York (10), Virginia (9), Rhode Island (9), and Florida (9). The states with the fewest attributes are Hawaii (2), Louisiana (4), Texas (4), and New Hampshire (4).

Table 5. Oyster-Specific Regulatory Environment Score Results. A "Y" (highlighted in green) indicates that the state has a particular attribute and is the only entry that received a score of 1.0. An "N" (red) represents those states that do not have an attribute and received a 0; states with "No data" (white) also received a 0 as no information could be found using the search methodology. "C" (yellow) represents a conditional, which, in some instances, such as a commonwealth's jurisdiction, may include or exclude that characteristic, and also received a 0. The total possible score is 12 within the Oyster-Specific Regulatory Environment Score and 1.0 for the Final Oyster Aquaculture Score. Table 5 continues vertically to show all attributes.

State	Oyster Gardening	Aquaculture Parks	State Training	Insurance Requirement	Transferable Lease	Active Use Criteria	Residency Requirement
AL	Y	Y	Y	N	Y	N	N
AK	N	N	Y	Y	Y	Y	N
CA	N	N	N	N	Y	Y	N
CT	No Info	No Info	Y	N	Y	Y	C
DE	Y	Y	Y	N	Y	Y	N
FL	Y	Y	Y	N	Y	Y	N
GA	No Info	N	Y	Y	Y	Y	N
HI	N	N	N	No Info	No Info	No Info	N
LA	No Info	N	Y	N	Y	N	Y
ME	No Info	N	C	N	Y	Y	N
MD	Y	No Info	Y	Y	Y	Y	N
MA	Y	Y	N	N	Y	Y	C
MS	N	Y	C	Y	Y	Y	Y
NH	No Info	N	N	N	Y	N	Y
NJ	N	Y	Y	N	Y	N	Y
NY	Y	Y	N	N	Y	Y	Y
NC	Y	N	Y	N	Y	Y	N
OR	N	Y	N	N	Y	Y	N
RI	Y	N	Y	Y	Y	Y	N
SC	No Info	N	Y	N	N	Y	Y
TX	N	N	N	N	N	Y	Y
VA	Y	Y	Y	N	Y	Y	Y
WA	Y	N	Y	N	Y	Y	N
Percent	43%	39%	61%	22%	87%	78%	35%

State	Joint Permit Application (JPA)	Applicant Guide	Process Flow Chart	Operational Plan Requirement	Financial Plan Requirement	Total Attributes per State	Final Oyster-Specific Regulatory Environment Score
AL	Y	Y	N	Y	N	7	0.58
AK	N	Y	Y	Y	N	7	0.58
CA	N	Y	Y	Y	N	5	0.42
CT	Y	Y	Y	Y	N	7	0.58
DE	Y	Y	N	C	C	7	0.58
FL	N	Y	Y	Y	Y	9	0.75
GA	N	Y	N	Y	Y	7	0.58
HI	N	Y	N	Y	N	2	0.17
LA	Y	N	N	N	N	4	0.33
ME	Y	Y	Y	Y	Y	7	0.58
MD	Y	Y	N	Y	N	8	0.67
MA	N	Y	N	Y	C	6	0.50
MS	Y	N	N	Y	Y	8	0.67
NH	N	Y	N	Y	N	4	0.33
NJ	N	Y	N	Y	N	6	0.50
NY	Y	Y	Y	Y	Y	10	0.83
NC	N	Y	Y	Y	Y	7	0.58
OR	Y	Y	Y	Y	N	7	0.58
RI	Y	Y	Y	Y	N	9	0.75
SC	Y	N	Y	Y	Y	7	0.58
TX	N	Y	N	Y	N	4	0.33
VA	Y	Y	N	Y	N	9	0.75
WA	Y	Y	Y	Y	N	8	0.67
Percent	57%	87%	48%	91%	30%		

3.3. Results and Scoring of Final Oyster Aquaculture Score

Among regional averages, the Mid-Atlantic (2.44) and New England (2.31) had the highest regional averages, while the Western Pacific (0.96) and the Gulf of Mexico (1.62) had the lowest (Table 6). These final scores were summed from each of the four index components and reflect an overall industry climate based on policy, GIS tools, production, and data availability across time.

Table 6. Index scoring is divided into NMFS regional offices. Florida is used in averaging for both the Gulf of Mexico and the South Atlantic due to Florida being split into Gulf and Atlantic coasts for many fishery-related databases and categorization. Green colors indicate higher scores, while red colors indicate lower scores. Heatmaps are colored by column.

Region	Policy Enabling Score [27]	Shellfish Map Viewer Score [28]	Oyster Production Quantitative Score	Oyster-Specific Regulatory Environment	Regional Average Total
North Pacific	0.81	0.00	0.45	0.58	1.84
Pacific	0.65	0.26	0.64	0.56	2.10
Western Pacific	0.56	0.00	0.23	0.17	0.96
New England	0.54	0.64	0.59	0.55	2.31
Mid-Atlantic	0.74	0.56	0.47	0.67	2.44
South Atlantic	0.67	0.36	0.40	0.62	2.05
Gulf of Mexico	0.50	0.22	0.36	0.53	1.62

4. Discussion

4.1. Regional Comparisons

At the regional level, the Mid-Atlantic and New England regions yielded the highest scores, performing strongly across all four index components. For the Mid-Atlantic, the lowest scoring index component was the Oyster Production Quantitative Score, which is similar to the results found among the highest-performing states. For New England, the lowest scoring indices were the Regional Policy Enabling Score and the Oyster-Specific Regulatory Environment, indicating that this region has relatively lower numbers of policy attributes focused on aquaculture broadly (including finfish and shellfish) as well as oysters specifically. This may be due to the region already having active and growing aquaculture industries without the need for additional legislation to guide industry growth.

The two lowest-performing regions were the Gulf of Mexico and the Western Pacific. Some states in the Gulf of Mexico have only recently begun the implementation of oyster aquaculture (the first commercial farm in Texas in operation 2021; the first commercial farm in Mississippi in operation in 2019) [32], while others have favored wild harvest over caged aquaculture. Louisiana, listed as the state with the highest acreage devoted to oyster farming according to the State-by-State Summary of Shellfish Aquaculture Leasing/Permitting Requirements [26], has nine of the top ten commercial harvests by value ever recorded by the NMFS Fisheries One Stop Shop as of January 2025 [33]. This result is substantially different than average oyster harvest data recorded in the USDA Census of Aquaculture. Compared to the Gulf of Mexico, states in the Mid-Atlantic and New England regions have a long history of the regulation of commercial oyster farming: the Oyster Act of 1844 in Rhode Island [34], or the "One-Acre Planting Law" of 1830 in Maryland [35]. The Western Pacific region only encompasses Hawaii, where oyster farming might not be economically viable and features a high pressure for coastal space [36–38].

As one of the four parts of the index, the Shellfish Map Viewer scored among the lowest among the four index components. In some cases, these data are retained by natural resource management agencies for their management use rather than for public access. Other situations also include state health organizations retaining the GIS tools for use in food safety, a single-use tool rather than data sharing. This component of the index is likely to change as the use of GIS has become more accessible, and also contributes to the development of support tools, decision making, siting, and modeling for oyster aquaculture [29,39,40]. Some states, such as Alaska and Florida, which had no shellfish GIS data available to the public at the time of the study, still scored highly because of ample policy attributes focused on enabling aquaculture. Both states have recently developed publicly available shellfish GIS viewers that would significantly enhance their overall score in the future [41,42].

4.2. Regional Differences in Fishery Management

Despite notable similarities in the structural frameworks of fishery and aquaculture management organizations, recent studies have highlighted nuanced differences in the levels of collaborative engagement and trust between state natural resource managers and various other organizations [43–46]. These variations not only shape the dynamics of interorganizational relationships, but also influence the collective capacity and willingness to cooperate in complex regulatory environments, such as aquaculture, where permitting and oversight are required across multiple levels of governance [43,47].

Using the regional approach from the study's index, the Mid-Atlantic and New England represent areas with a long history of assigning cultural significance to shellfish species. These areas, particularly the Chesapeake, feature some of the most well-documented and abundant oysters within archeological sites in North America [48]. Oyster middens in these areas provide physical evidence of native people's consumption of oysters approximately 3200 years ago, providing a record of culturally and scientifically significant sites tied to human demography and the environment [49,50]. European settlement expansion and population growth can be tied to midden distributions along the coast and moving away from early northeast settlements [50,51]. Human population dynamics and their effects on oysters have also been observed on the United States' western coast, but with a smaller population [48,52].

The long history of oyster consumption in these regions may have enabled a greater cultural awareness of oysters in general than in other geographic regions, which may have increased the development of resources to promote oyster aquaculture. In contrast, moderate- and lower-scoring regions may have emphasized regional food commodities with greater cultural and commercial importance, such as crawfish in Louisiana [53,54] or lobsters in Maine [55,56]. There may be less of a political and financial will to implement oyster aquaculture when other favorable alternatives exist due to local cultural preferences, economies, and environments [57,58].

4.3. Limitations of an Index-Based Approach and Data Management

Oyster aquaculture is a complex and dynamic industry. Whereas research within oyster aquaculture policy is generally published on case studies within states or smaller geographies, this study used a mixed methods approach to generate a broad view of oyster aquaculture in the U.S. Challenges to this approach include the constantly developing landscape of aquaculture within each state that presents a "moving target", whereas the data used represent a snapshot in time. Technical definitions and reporting approaches used within the industry may also differ among states, which may lead to different interpretations of survey questions (i.e., need for clarity when considering private leases and/or "cultch on bottom" as aquaculture) [59]. Given these challenges, the integrated scores may better convey differences within and among states and regions by identifying and combining a suite of input variable (e.g., policy attributes, resource availability) metrics into a single index. Index approaches are useful when comparing abstract phenomena that cannot be simply described or measured and feature a multitude of qualitative and quantitative data that must be organized and synthesized to be understood [60,61].

Improved data management can benefit the oyster aquaculture industry as well as policymakers concerned with oyster aquaculture. One of the primary sources, the USDA Census of Aquaculture, has shown significant advances from previous survey methodology to include questions that are also focused on ecology and spatial planning [17]. The collection of these data supports research involving land use and ecosystem services of aquaculture species [62]. Increasing the frequency of the USDA Census of Aquaculture can increase the resolution of data, which may be particularly important when identifying the impacts of natural disasters or other significant changes to aquaculture capacity [63–65]. The NMFS Commercial Fisheries Landings provides an excellent delineation of shellfish species for commercial and recreational harvests but does not contain aquaculture species [33]. Developing or integrating a unified framework with standardized terminology, coupled with more frequent and targeted data collection, can enhance our understanding of nationwide large-scale management efforts and better support sustainable domestic seafood initiatives [8,66].

5. Conclusions

This study addresses a critical gap in the research by offering one of the few nationwide comparisons of oyster aquaculture. By developing a four-part index, this analysis provides a comprehensive evaluation of environmental, regulatory, and economic factors influencing oyster aquaculture across U.S. states. The findings highlight that the Mid-Atlantic and New England regions exhibit the most favorable conditions for a thriving oyster aquaculture industry. These insights offer valuable guidance for states with less developed industries, and for academic institutions to identify specific areas for improvement and resource allocation. By leveraging the insights gained from this index and enhancing information-sharing mechanisms, policymakers, researchers, and industry stakeholders can work toward a more efficient, widely accepted, and economically viable aquaculture sector.

A key consideration for the future of oyster aquaculture is the refinement of data collection methodologies. Current data collection efforts are often fragmented, with state agencies gathering some production metrics that may not be publicly available and national agencies such as USDA and NMFS recording data sporadically and with limited focus. Standardized and systematically updated survey methodologies could resolve these gaps in knowledge, providing a stronger foundation for decision making and policy development. A more robust data collection framework would also facilitate comparisons across states, ensuring that aquaculture expansion is based on reliable high-quality information to guide decision making. Expanding such initiatives into a nationally coordinated database could streamline data access, improve regulatory transparency, and advocate for the broader support of sustainable shellfish aquaculture.

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References

1. Wilberg, M.J.; Livings, M.E.; Barkman, J.S.; Morris, B.T.; Robinson, J.M. Overfishing, Disease, Habitat Loss, and Potential Extirpation of Oysters in Upper Chesapeake Bay. *Mar. Ecol. Prog. Ser.* **2011**, *436*, 131–144. [CrossRef]
2. Beck, M.W.; Brumbaugh, R.D.; Airoldi, L.; Carranza, A.; Coen, L.D.; Crawford, C.; Defeo, O.; Edgar, G.J.; Hancock, B.; Kay, M.C.; et al. Oyster Reefs at Risk and Recommendations for Conservation, Restoration, and Management. *BioScience* **2011**, *61*, 107–116. [CrossRef]
3. Parker, M.; Bricker, S. Sustainable Oyster Aquaculture, Water Quality Improvement, and Ecosystem Service Value Potential in Maryland Chesapeake Bay. *J. Shellfish. Res.* **2020**, *39*, 269–281. [CrossRef]
4. Bricker, S.B.; Grizzle, R.E.; Trowbridge, P.; Rose, J.M.; Ferreira, J.G.; Wellman, K.; Zhu, C.; Galimany, E.; Wikfors, G.H.; Saurel, C.; et al. Bioextractive Removal of Nitrogen by Oysters in Great Bay Piscataqua River Estuary, New Hampshire, USA. *Estuaries Coasts* **2020**, *43*, 23–38. [CrossRef]
5. Lima, A.R.; Pollack, J.; Fox, J.M.; Ferreira, J.G.; Cubillo, A.M.; Reisinger, A.; Bricker, S. Developing Nitrogen Bioextraction Economic Value via Off-Bottom Oyster Aquaculture in the Northwestern Gulf of Mexico. *Mar. Pollut. Bull.* **2025**, *211*, 117396. [CrossRef]
6. Luckenbach, M.W.; Mann, R.; Wesson, J.A. Oyster Reef Habitat Restoration: A Synopsis and Synthesis of Approaches. In Proceedings of the Symposium, Williamsburg, VA, USA, April 1995. [CrossRef]
7. Peterson, C.H.; Grabowski, J.H.; Powers, S.P. Estimated Enhancement of Fish Production Resulting from Restoring Oyster Reef Habitat: Quantitative Valuation. *Mar. Ecol. Prog. Ser.* **2003**, *264*, 249–264. [CrossRef]
8. Fisheries, N. National Shellfish Initiative | NOAA Fisheries. Available online: https://www.fisheries.noaa.gov/national/aquaculture/national-shellfish-initiative (accessed on 14 March 2025).
9. Naylor, R.L.; Hardy, R.W.; Bureau, D.P.; Chiu, A.; Elliott, M.; Farrell, A.P.; Forster, I.; Gatlin, D.M.; Goldburg, R.J.; Hua, K.; et al. Feeding Aquaculture in an Era of Finite Resources. *Proc. Natl. Acad. Sci. USA* **2009**, *106*, 15103–15110. [CrossRef]
10. Barrett, L.T.; Theuerkauf, S.J.; Rose, J.M.; Alleway, H.K.; Bricker, S.B.; Parker, M.; Petrolia, D.R.; Jones, R.C. Sustainable Growth of Non-Fed Aquaculture Can Generate Valuable Ecosystem Benefits. *Ecosyst. Serv.* **2022**, *53*, 101396. [CrossRef]
11. Nelson, K.A.; Leonard, L.A.; Posey, M.H.; Alphin, T.D.; Mallin, M.A. Using Transplanted Oyster (*Crassostrea virginica*) Beds to Improve Water Quality in Small Tidal Creeks: A Pilot Study. *J. Exp. Mar. Biol. Ecol.* **2004**, *298*, 347–368. [CrossRef]
12. Jones, A.B.; Preston, N.P. Sydney Rock Oyster, (Iredale & Roughley), Filtration of Shrimp Farm Effluent: The Effects on Water Quality. *Aquac. Res.* **1999**, *30*, 51–57. [CrossRef]
13. Grabowski, J.H.; Peterson, C.H. Restoring Oyster Reefs to Recover Ecosystem Services. *Theor. Ecol. Ser.* **2007**, *4*, 281–298.
14. FAO. *The State of World Fisheries and Aquaculture 2024*; FAO: Rome, Italy, 2024; ISBN 978-92-5-138763-4.
15. National Marine Fisheries Service. *2020 Fisheries of the United States*. 2022. Available online: https://s3.amazonaws.com/media.fisheries.noaa.gov/2025-01/FUS-2022-final3.pdf (accessed on 14 March 2025).
16. USDA. 2012–2013 Census of Aquaculture–AgCensus. Available online: https://agcensus.library.cornell.edu/census_parts/2012-2013-census-of-aquaculture/ (accessed on 14 March 2025).
17. USDA. 2018 Census of Aquaculture. Available online: https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Aquaculture/index.php (accessed on 14 March 2025).
18. USDA. 2023 Census of Aquaculture. Available online: https://www.nass.usda.gov/Publications/AgCensus/2022/Online_Resources/Aquaculture/index.php (accessed on 14 March 2025).
19. Clyde, L.M. History of Oystering in the United States and Canada, Featuring the Eight Greatest Oyster Estuaries. *Mar. Fish. Rev.* **1996**, *58*, 1–79.
20. Lavoie, R.E. Oyster Culture in North America: History, Present and Future 2009. Available online: https://worldoyster.org/wp/wp-content/uploads/2019/04/news_17e.pdf (accessed on 14 March 2025).
21. Botta, R.; Asche, F.; Borsum, J.S.; Camp, E.V. A Review of Global Oyster Aquaculture Production and Consumption. *Mar. Policy* **2020**, *117*, 103952. [CrossRef]
22. Izraelov, M.; Silber, J. An Assessment of the Global Food Security Index. *Food Sec.* **2019**, *11*, 1135–1152. [CrossRef]
23. Valizadeh, N.; Hayati, D. Development and Validation of an Index to Measure Agricultural Sustainability. *J. Clean. Prod.* **2021**, *280*, 123797. [CrossRef]
24. Movilla-Pateiro, L.; Mahou-Lago, X.M.; Doval, M.I.; Simal-Gandara, J. Toward a Sustainable Metric and Indicators for the Goal of Sustainability in Agricultural and Food Production. *Crit. Rev. Food Sci. Nutr.* **2021**, *61*, 1108–1129. [CrossRef]

25. Fishery Health Index Progress Score–Food Systems Dashboard. Available online: https://www.foodsystemsdashboard.org/indicators/outcomes/environmental-impacts/fishery-health-index-progress-score (accessed on 13 March 2025).
26. NMFS. Report-State-by-State-Summary-of-Shellfish-Aquaculture-Leasing-Permitting-Requirements-2021. Available online: https://www.fisheries.noaa.gov/s3//2021-09/Report-State-by-State-Summary-of-Shellfish-Aquaculture-Leasing-Permitting-Requirements-2021.pdf (accessed on 14 March 2025).
27. Lester, S.E.; Gentry, R.R.; Lemoine, H.R.; Froehlich, H.E.; Gardner, L.D.; Rennick, M.; Ruff, E.O.; Thompson, K.D. Diverse State-Level Marine Aquaculture Policy in the United States: Opportunities and Barriers for Industry Development. *Rev. Aquac.* **2022**, *14*, 890–906. [CrossRef]
28. Wickliffe, L.C.; Crothers, V.C.; Theuerkauf, S.J.; Riley, K.L.; Morris, J.A. Shellfish Aquaculture Map Viewers: An Assessment of Design, Data, and Functions to Inform Planning and Siting in the United States. *J. Shellfish. Res.* **2019**, *38*, 209–221. [CrossRef]
29. Silva, C.; Ferreira, J.G.; Bricker, S.B.; DelValls, T.A.; Martín-Díaz, M.L.; Yáñez, E. Site Selection for Shellfish Aquaculture by Means of GIS and Farm-Scale Models, with an Emphasis on Data-Poor Environments. *Aquaculture* **2011**, *318*, 444–457. [CrossRef]
30. Bricker, S.B.; Getchis, T.L.; Chadwick, C.B.; Rose, C.M.; Rose, J.M. Integration of Ecosystem-Based Models into an Existing Interactive Web-Based Tool for Improved Aquaculture Decision-Making. *Aquaculture* **2016**, *453*, 135–146. [CrossRef]
31. Saurel, C.; Taylor, D.P.; Tetrault, K. Bivalve Gardening. In *Goods And Services of Marine Bivalves*; Springer: Cham, Switzerland, 2019; ISBN 978-3-319-96776-9.
32. Walton, W.C.; Swann, L. Role of Sea Grant in Establishing Commercial Oyster Aquaculture through Applied Research and Extension. *J. Contemp. Water Res. Educ.* **2021**, *174*, 171–179. [CrossRef]
33. Fisheries One Stop Shop (FOSS) | NOAA Fisheries | Landings. Available online: https://www.fisheries.noaa.gov/foss/f?p=215:200:::::: (accessed on 14 March 2025).
34. Rice, M.A. A Brief History of Oyster Aquaculture in Rhode Island. Rhode Island Coastal Resources Management Council. *Aquac. Rhode Isl.* **2006**, 24–38. Available online: http://www.crmc.ri.gov/aquaculture/aquareport06.pdf (accessed on 13 March 2025).
35. Torres-Soto, E. A Comparative Analysis of Maryland's Public Participation Framework in Commercial Shellfish Aquaculture Leasing: Standing to Present Protests. *Sea Grant L. Pol'y J.* **2021**, *11*, 101–132.
36. A Technical Efficiency Analysis of Hawaii's Aquaculture Industry–Arita–2014–Journal of the World Aquaculture Society–Wiley Online Library. Available online: https://onlinelibrary.wiley.com/doi/abs/10.1111/jwas.12124 (accessed on 13 March 2025).
37. Chen, J.Q.; Haws, M.C.; Fong, Q.S.W.; Leung, P. Economic Feasibility of Producing Oysters Using a Small-Scale Hawaiian Fishpond Model. *Aquac. Rep.* **2017**, *5*, 41–51. [CrossRef]
38. Flannery, W.; Healy, N.; Luna, M. Exclusion and Non-Participation in Marine Spatial Planning. *Mar. Policy* **2018**, *88*, 32–40. [CrossRef]
39. Bendell, L.I.; Wan, P.C.Y. Application of Aerial Photography in Combination with GIS for Coastal Management at Small Spatial Scales: A Case Study of Shellfish Aquaculture. *J. Coast. Conserv.* **2011**, *15*, 417–431. [CrossRef]
40. Development of a Siting Tool for Sustainable Oyster Aquaculture in Texas. Available online: https://coastalscience.noaa.gov/project/development-of-a-siting-tool-for-sustainable-oyster-aquaculture-in-texas/ (accessed on 14 March 2025).
41. Alaska Department of Fish and Game ArcGIS Web Application. Available online: https://adfg.maps.arcgis.com/apps/webappviewer/index.html?id=f3ca95493c1042b39e42a3ecb5dcad6a&_ga=2.262224652.1637086420.1691677984-320870341.1691677984 (accessed on 13 March 2025).
42. Florida Department of Agriculture and Consumer Services. Shellfish Harvesting Area and Aquaculture Lease Map/Aquaculture/Agriculture Industry/Home–Florida Department of Agriculture & Consumer Services. Available online: https://www.fdacs.gov/Agriculture-Industry/Aquaculture/Shellfish-Harvesting-Area-and-Aquaculture-Lease-Map (accessed on 14 March 2025).
43. Temby, O.; Sandall, J.; Cooksey, R.; Hickey, G.M. Examining the Role of Trust and Informal Communication on Mutual Learning in Government: The Case of Climate Change Policy in New York. *Organ. Environ.* **2017**, *30*, 71–97. [CrossRef]
44. Lima, A.; Kim, D.; Song, A.M.; Hickey, G.M.; Temby, O. Trust and Influence in the Gulf of Mexico's Fishery Public Management Network. *Sustainability* **2019**, *11*, 6090. [CrossRef]
45. Hickey, G.M.; Roozee, E.; Voogd, R.; de Vries, J.R.; Sohns, A.; Kim, D.; Temby, O. On the Architecture of Collaboration in Inter-Organizational Natural Resource Management Networks. *J. Environ. Manag.* **2023**, *328*, 116994. [CrossRef]
46. Katznelson, D.; Sohns, A.; Kim, D.; Roozee, E.; Donner, W.R.; Song, A.M.; de Vries, J.R.; Temby, O.; Hickey, G.M. Examining the Presence and Effects of Coherence and Fragmentation in the Gulf of Maine Fishery Management Network. *Reg. Environ. Change* **2024**, *25*, 3. [CrossRef]
47. Temby, O.; Rastogi, A.; Sandall, J.; Cooksey, R.; Hickey, G.M. Interagency Trust and Communication in the Transboundary Governance of Pacific Salmon Fisheries. *Rev. Policy Res.* **2015**, *32*, 79–99. [CrossRef]
48. Reeder-Myers, L.; Braje, T.J.; Hofman, C.A.; Elliott Smith, E.A.; Garland, C.J.; Grone, M.; Hadden, C.S.; Hatch, M.; Hunt, T.; Kelley, A.; et al. Indigenous Oyster Fisheries Persisted for Millennia and Should Inform Future Management. *Nat. Commun.* **2022**, *13*, 2383. [CrossRef] [PubMed]

49. Darrow, E.S.; Carmichael, R.H.; Andrus, C.F.T.; Jackson, H.E. From Middens to Modern Estuaries, Oyster Shells Sequester Source-Specific Nitrogen. *Geochim. Cosmochim. Acta* **2017**, *202*, 39–56. [CrossRef]
50. Rick, T.C.; Reeder-Myers, L.A.; Carr, M.J.; Hines, A.H. 3000 Years of Human Subsistence and Estuarine Resource Exploitation on the Rhode River Estuary, Chesapeake Bay, Maryland. *J. N. Atl.* **2017**, *10*, 113–125. [CrossRef]
51. Marquardt, W.H. Shell Mounds in the Southeast: Middens, Monuments, Temple Mounds, Rings, or Works? *Am. Antiq.* **2010**, *75*, 551–570. [CrossRef]
52. Kirby, M.X. Fishing down the Coast: Historical Expansion and Collapse of Oyster Fisheries along Continental Margins. *Proc. Natl. Acad. Sci. USA* **2004**, *101*, 13096–13099. [CrossRef]
53. Gutierrez, C.P. The Social and Symbolic Uses of Ethnic/Regional Foodways. In *Mardi Gras, Gumbo, and Zydeco: Readings in Louisiana Culture*; University Press of Mississippi: Jackson, MS, USA, 2003; ISBN 978-1-57806-530-1.
54. Mcclain, W.R.; Romaire, R.P. Crawfish Culture: A Louisiana Aquaculture Success Story. *World Aquac.* **2004**, *35*, 31–35.
55. Harrington, R.J. Defining Gastronomic Identity: The Impact of Environment and Culture on Prevailing Components, Texture and Flavors in Wine and Food. *J. Culin. Sci. Technol.* **2005**, *4*, 129–152. [CrossRef]
56. Love, D.C.; Asche, F.; Young, R.; Nussbaumer, E.M.; Anderson, J.L.; Botta, R.; Conrad, Z.; Froehlich, H.E.; Garlock, T.M.; Gephart, J.A.; et al. An Overview of Retail Sales of Seafood in the USA, 2017–2019. *Rev. Fish. Sci. Aquac.* **2022**, *30*, 259–270. [CrossRef]
57. Malmberg, A.; Maskell, P. Towards an Explanation of Regional Specialization and Industry Agglomeration. *Eur. Plan. Stud.* **1997**, *5*, 25–41. [CrossRef]
58. Coşar, A.K.; Fajgelbaum, P.D. Internal Geography, International Trade, and Regional Specialization. *Am. Econ. J. Microecon.* **2016**, *8*, 24–56. [CrossRef]
59. Wirth, F.F.; Minton, T.M. A Review of the Market Structure of the Louisiana Oyster Industry: A Microcosm of the United States Oyster Industry. *J. Shellfish Res.* **2004**, *23*, 841–848.
60. Othman, A.A.E. An International Index for Customer Satisfaction in the Construction Industry. *Int. J. Constr. Manag.* **2015**, *15*, 33–58. [CrossRef]
61. Singh, R.K.; Kumar, P.; Chand, M. Evaluation of Supply Chain Coordination Index in Context to Industry 4.0 Environment. *Benchmarking Int. J.* **2019**, *28*, 1622–1637. [CrossRef]
62. Cross, S.F. Diversification of aquaculture in North America. In *Planning for Aquaculture Diversification: The Importance of Climate Change and Other Drivers*; FAO: Rome, Italy, 2017.
63. van Senten, J.; Engle, C.R.; Smith, M.A. Effects of COVID-19 on U.S. Aquaculture Farms. *Appl. Econ. Perspect. Policy* **2021**, *43*, 355–367. [CrossRef]
64. Gladju, J.; Kamalam, B.S.; Kanagaraj, A. Applications of Data Mining and Machine Learning Framework in Aquaculture and Fisheries: A Review. *Smart Agric. Technol.* **2022**, *2*, 100061. [CrossRef]
65. Gangnery, A.; Bacher, C.; Boyd, A.; Liu, H.; You, J.; Strand, Ø. Web-Based Public Decision Support Tool for Integrated Planning and Management in Aquaculture. *Ocean Coast. Manag.* **2021**, *203*, 105447. [CrossRef]
66. Frankic, A.; Hershner, C. Sustainable Aquaculture: Developing the Promise of Aquaculture. *Aquac. Int.* **2003**, *11*, 517–530. [CrossRef]