



Labor dynamics in Florida and Virginia shellfish aquaculture

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ABSTRACT

Bivalve shellfish aquaculture has made a significant economic impact on rural US coastal communities in recent decades, with potential to satisfy global food demands by providing a nutrient dense, resource efficient product; industry expansion, however, may be limited by socio-economic, environmental, and ecological constraints. Eastern oyster (*Crassostrea virginica*) and hard clam (*Mercenaria mercenaria*) industries have the potential for large scalability, though production may be limited by labor availability, working conditions, and physical demands. Labor demands in shellfish aquaculture were measured to assess production efficiencies, technological substitutions, and optimal workforce development for Virginia and Florida commercial oyster and hard clam farms. Semi-structured interviews with employers and employees were conducted to evaluate perceptions on labor availability, job satisfaction, labor-reducing technologies, stressors, and industry growth. Descriptive and inferential analyses identified emergent themes among the interviews, and helped to understand industry growth, change, and constraint. The results depict that shellfish aquaculture labor needs can be impacted by multiple factors like location, operation scale, production method, and species produced. Interviewees suggested that public perception and market demands are significant for stimulating industry growth. This study provides insight into the dynamicity of labor needs and technological advancements in the bivalve shellfish aquaculture industry, which must be considered for supporting a blue economy and industry growth.

1. Introduction

1.1. Global and US aquaculture socio-economic impacts

The global population is expected to increase to 10 B individuals by 2050 and a significant increase in global food supply will be necessary to fulfill food demands. Seafood production could play a significant role in meeting global food demands and ensuring food security but requires a critical evaluation of production and consumption patterns. Current aquatic food consumption rates are estimated at 20.7 kg per year, which is double the 1970 consumption rate, with a five-fold increase in global seafood production from 1960 to 2010 (FAO, 2024; Kite-Powell et al., 2013). Roughly 94 M tons of aquaculture product worth ~296B USD was produced in 2022, which is a remarkable increase from the 22 M tons of aquaculture product that was produced in the 1990s (FAO, 2024). In comparison, wild capture fisheries roughly produced 91 M tons of product worth ~157B USD in 2022 (FAO, 2024). This was the first instance that aquaculture production surpassed capture fisheries production globally (FAO, 2024), which highlights the shift of industry expansion to support growing food demands. In 2022, 36% of 61.8 M

jobs in the global fishing and aquaculture industry were supported by the aquaculture sector (FAO, 2024). Continued expansion of the aquaculture industry could reduce seafood production costs, potentially increasing product availability and enhancing global food security (Bjørndal et al., 2024).

In the United States (US) specifically, estimates indicate that 90% of seafood is imported, with 50% of seafood grown through aquaculture (Lipton et al., 2019). The US aquaculture industry is widely diversified with species and production methods, though it is relatively small in global comparison to other aquaculture industries (FAO, 2022). In 2022, US aquaculture farms were estimated to have contributed \$4B annually to the economy, supporting over 22,000 jobs from direct (e.g., an oyster farmer), indirect (e.g., a gear manufacturer), and induced employment (e.g., restaurant staff), while generating a total labor income of \$1B (Kumar et al., 2024). Furthermore, Kite-Powell et al. (2013) indicate that for each additional \$100K in aquaculture farm production, three or more jobs were provided. Of the most economically important aquaculture species produced in the US, molluscs placed 2nd and 4th, with oysters in 2nd, behind catfish, and clams in 4th, behind salmonids (Kumar et al., 2024). Mollusc aquaculture farms contributed \$0.84B to

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the US economy in 2022 and supported over 5000 jobs (Kumar et al., 2024). According to the 2023 USDA Census of Aquaculture (USDA National Agricultural Statistics Service [USDA-NASS], 2024), 1140 farms produced bivalve shellfish - including abalone, clams, mussels, oysters, and other molluscs - totaling \$575.4M in annual revenue.

With increased seafood consumption, expanded production in the aquaculture sector is being evaluated given the limited capacity for growth in terrestrial animal protein sectors (Costello et al., 2020). Advancing aquaculture industries in an environmentally sustainable manner could aid in improving ecological, economic, and social conditions globally (Alleway et al., 2019). Bivalve shellfish aquaculture has the potential to help satisfy global food demands, as a sustainable food source that can enhance food security, support fisheries, and provide a nutrient dense, resource efficient product (Hilborn et al., 2018; Naylor et al., 2021). The practice of bivalve shellfish aquaculture aligns with the United Nations' Goal 14 (Life Below Water) to protect, restore, and conserve marine ecosystems, increase economic benefits from marine resources, support food security and fishing communities, protect overfished fish stocks, and improve regulatory frameworks (UN DESA, 2024). Shellfish aquaculture supports this goal by providing regulating services (e.g., water filtration), provisioning services (e.g., food), cultural services (e.g., employment), and habitat and supporting services (e.g., genetic diversity) (Alleway et al., 2019).

Shellfish aquaculture has great potential for scalability, though labor needs and workforce constraints associated with industry expansion are understudied. Physical labor demands and expansion of available workforce are considered significant challenges for globally expanding shellfish aquaculture due to recent labor shortages, increasing labor costs, and variable working conditions per farm (Chen et al., 2017; Engle et al., 2021; Girard and Agúndez, 2014).

A broader understanding of socio-economic, environmental, and ecological interactions within the shellfish aquaculture industry are required to identify and comprehend current and future challenges (Holden et al., 2019). Despite the recognized need for holistic understanding, attention to the social and economic dimensions of aquaculture is lacking and should be acknowledged in conjunction with other pressing issues (e.g., linking the environmental footprint from aquaculture to human well-being; Bjørndal et al., 2024; Brugere et al., 2023). Challenges identified in the literature for expanding global shellfish aquaculture production include, but are not limited to, climate change implications (e.g., acidification, warming temperatures, increasing storm intensity), economic viability, social perceptions, desirable/suitable space for expansion, legislation and management decisions, direct or indirect interactions with existing industries, labor availability, and labor demands (Brugere et al., 2023; Fox et al., 2020; Heasman et al., 2020; Holden et al., 2019; Rubino, 2023; Schultz et al., 2024).

1.2. Labor availability in shellfish aquaculture

Labor demands in bivalve shellfish aquaculture are not well understood due to the difficulty of quantifying time requirements, work intensity, injuries, technological substitutability, and the diversity of farms and production methods involved. Economic tradeoffs for production methods (Engle et al., 2021; Hood et al., 2020), multi-faceted stressors impacting production (Fox et al., 2020; Green et al., 2023; Moor et al., 2022; Pei et al., 2025; Stewart-Sinclair et al., 2020), and labor-reducing technological advancements in the industry (Chowdhury et al., 2025; Kumar et al., 2018; Shenghu et al., 2025) have been studied. Labor requirements are variable by species produced, location, and scale, and the availability of skilled labor is crucial for supporting sustained development of the US aquaculture sector (Rubino, 2008). Shellfish aquaculture is typically practiced in rural, coastal regions, where spatial use conflicts are lessened and costs for land-based facilities are more affordable; however, such areas are often considered economically disadvantaged and typically maintain lower population densities. Therefore, spatial mismatch between labor supply and labor

demands can be a challenge (Kapetsky and Aguilar-Manjarrez, 2013). Employing seasonal migrant labor has become an additional strategy for augmenting labor supply, though to hire migrant labor, the employer must prove that there are limited US workers able, willing, and available to work at the business, along with other qualifications (U.S. Citizenship and Immigration Services [USCIS], 2025a; U.S. Citizenship and Immigration Services [USCIS], 2025b). Additionally, unpaid family and other volunteer labor is likely used across the industry (Engle et al., 2021).

Automation, the adoption of new technologies to substitute or reduce labor needs, has become increasingly popular for enhancing productivity across working industries through industrial machinery, software, and artificial intelligence (Acemoglu and Restrepo, 2019). Automation in aquaculture has developed and advanced rapidly in recent decades, such as genome editing, updated vaccinations, recirculating aquaculture systems, and digital technologies (Yue and Shen, 2022). Shellfish hatcheries and nurseries are more efficient with equipment like indoor nursery systems, automated feeding devices, and water exchange systems (Shenghu et al., 2025), along with the use of algae concentrates and substitutes to reduce production costs (Aji, 2011). The processing side of the shellfish industry has also experienced advanced mechanization; for example, mechanization of grading has created a 30-fold efficiency gain over manually sorting shellfish (Shenghu et al., 2025). Mechanizing shellfish aquaculture through technological advances could improve production efficiency, mitigate labor shortages, reduce labor intensity of workers, improve product quality and safety, and sustainably maintain the industry (Shenghu et al., 2025).

Worker satisfaction is a factor to be considered for labor availability, specifically due to arduous and risky working conditions that often occur when working on a shellfish farm. Locke (1969) highlights Rand's theory of emotions, which underscores the concepts of satisfaction, dissatisfaction, value, emotion, and appraisal, and emphasizes that job satisfaction should be measured as the sum of evaluations of all job aspects. Similarly, Mobley (1977) describes a significant relationship between worker satisfaction, employee turnover, and intermediate linkages (e.g., cost/benefit of quitting, job re-evaluation) that should be assessed for employee retention. Job satisfaction and motivation to remain in the industry has been globally studied in various commercial fisheries (Anastasiou et al., 2014; Arias Schreiber and Gillette, 2021; Christy et al., 2021; Holland et al., 2019; Pollnac et al., 2012; Sall, 2012; Seara et al., 2017; Sweke et al., 2016; White et al., 2025) and aquaculture settings (Duc, 2008; Sweke et al., 2016) but data is limited on worker satisfaction in the bivalve shellfish aquaculture sector, specifically, with a handful of studies centered on motivation to enter the industry and linked job satisfaction (e.g., Cleaver et al., 2018; Lemoine et al., 2025; Michaelis et al., 2020; Michaelis et al., 2021; Stoll et al., 2019). It is important to consider how worker satisfaction may be impacted by limited labor availability, and, conversely, how labor availability could be impacted by worker satisfaction.

1.3. Oyster aquaculture

The US is the largest oyster producer in North America, farming several species of oyster, and ranked fourth for global production in terms of product weight (Botta et al., 2020; Gonçalves et al., 2024). In a recent estimate, there were 707 Eastern oyster farms and 175 Pacific oyster farms recorded in the US (USDA-NASS, 2024). Significant oyster production can be found on the East Coast, including Massachusetts, Maryland, Virginia, North Carolina, and Florida (Botta et al., 2023), and on the West Coast, though primarily in Washington, which dominates production as it accounts for nearly half of the US total (Lipton et al., 2019). Gear type is dependent on the region in which the oyster is produced, site-specific characteristics, and individual preferences. Production methods include traditional approaches such as planting oyster spat or seed on the seafloor, described as extensive culture, or the use of on-bottom gear (e.g., bottom cages) or floating gear (e.g., floating

cages), described as intensive culture (Botta et al., 2020). The number of shellfish farms and operation size varies by state. For example, West Coast production is dominated by two large shellfish operations, whereas East Coast production is diffused across hundreds of small to medium sized farms (Lipton et al., 2019). Eastern oysters (*Crassostrea virginica*) represented 26.4% of total mollusc aquaculture sales in the US, with \$151.9M in revenue, and Pacific oysters represented 26% of sales; totaling \$149.8M in revenue (USDA-NASS, 2024). Employment typically involves full-time, part-time, and seasonal labor, but there is considerable uncertainty for labor estimates. It was estimated that ~5600 jobs were supported by US oyster aquaculture in 2019 (Lipton et al., 2019).

1.4. Hard clam aquaculture

Like oyster aquaculture, clam aquaculture varies across US East and West coasts. In 2019, Washington was the largest producer of cultured clams in the US - estimated at 45% of US value. Hard clams (*Mercenaria mercenaria*) are the most common clam species produced on the East Coast (Marciello-Yepez et al., 2025). Florida and Virginia are major hard clam producers on the East Coast, comprising 15% and 17% of US production in 2014 (Lipton et al., 2019). Culture includes land-based grow out methods (e.g., raceways and tanks) and field-based grow out methods (e.g., planting directly on the sediment) (Whetstone et al., 2005). Field-based grow out methods are typically less expensive due to fewer materials and often use hard (e.g., pens, trays) or soft (e.g., bags, net covers) structure to reduce predation and to allow for easier harvest (Whetstone et al., 2005). Employment opportunities are similar to oyster aquaculture, where full-time, part-time, and seasonal positions exist; however, clam aquaculture is often less labor intensive compared to oyster aquaculture (Lipton et al., 2019). An estimated ~2000 jobs were supported by US clam aquaculture in 2019, with over 1000 jobs from direct employment, over 460 jobs from indirect employment, and over 560 jobs from induced employment (Lipton et al., 2019). In 2023, hard clams represented 18.3% of total mollusc aquaculture sales in the US, with \$105M in revenue across 261 farms (USDA-NASS, 2024).

1.5. Study aims

In this study, employer and employee perceptions are explored related to labor demands and availability, job satisfaction, stressors on labor productivity, labor-reducing technological advancements, and industry growth in Virginia and Florida's commercial bivalve shellfish aquaculture sectors. It is hypothesized that employer and employee perceptions vary by location, business scale, and species produced (oyster vs. hard clam), and that working in shellfisheries provides important non-material benefits (e.g., continuation of family heritage, lifestyle) that are key for balance against the increasing use of labor-saving technologies. These questions are approached using semi-structured interviews and qualitative analyses to understand growth, change, and constraints in these industries. The data collected in this study can be used to help inform expansion opportunities of the bivalve shellfish aquaculture industry, while assessing labor demands and potential labor-technology tradeoffs that may aid in expansion. Further expansion of the industry requires increased labor needs or greater usage of technologies to reduce labor demands. To heighten US production of bivalve shellfish aquaculture, it is expected that workforce and technological advancements will be needed to efficiently increase total product output. This research addresses key challenges for expanding the US bivalve shellfish aquaculture sector and adds to a limited body of literature on labor demands in shellfish aquaculture. Further understanding workforce needs and associated constraints in aquaculture can potentially provide insight to industry expansion opportunities to strengthen global food security and to support a blue economy.

2. Materials and methods

2.1. Study sites

Virginia and Florida are two of the largest shellfish producers in the US, with a combined total estimated at 23% of US shellfish production (USDA-NASS, 2024). These states were chosen due to the economic and non-material benefits that the shellfisheries provide in the Southeast region of the US. Interviews occurred with Eastern oyster and hard clam employers and employees located in Virginia's portion of the Chesapeake Bay (Western and Eastern Shore) and the Atlantic seaside, along with Florida's east and Gulf coasts.

2.1.1. Virginia

Virginia has an established hard clam industry and a large and mature Eastern oyster industry and ranks number one in the US for hard clam production and number one on the East Coast for oyster production (Gonçalves et al., 2024; Hudson, 2019; Hudson and White, 2025). The farm gate value for Virginia shellfish aquaculture in 2024 was \$81M (\$52M for hard clams and \$29M for Eastern oysters) and the industry provided over 500 full-time and 200 part-time jobs (Hudson and White, 2025), providing a source of income to many rural coastal communities in the state. Estimating the current labor pool for Virginia's oyster and hard clam industries is difficult due to the ambiguity of reporting labor. Concern regarding the available labor supply in Virginia's aquaculture industry has persisted for years (e.g., Sticker, 2007) and has led to the development of workforce training programs to increase the supply of laborers with skilled technical expertise in hatchery, nursery, and field settings (e.g., the Oyster Aquaculture Training program (est. 2009), an intensive five-month oyster aquaculture training program offered by the Aquaculture Genetics and Breeding Technology Center at the Virginia Institute of Marine Science). While true labor estimates remain a challenge within Virginia's shellfish aquaculture industry, the industry also faces constraints associated with social perceptions, production costs, permitting and regulation standards, environmental stressors (e.g., disease, temperature changes), and repeated unexplained mortality events (Beckensteiner et al., 2020; Guévelou et al., 2019).

2.1.2. Florida

Florida's hard clam aquaculture industry is also well-established, with oyster aquaculture developing quickly over the past decade. Oyster lease numbers increased from 15 registered leases in 2015 to 130 registered leases in 2020, due to a new regulation permitting the use of floating water column gear (Botta et al., 2023). In 2018, Florida reported 325 aquaculture farms (including all aquaculture products) with a total production value of \$71.6M (Botta et al., 2023). The state ranks third in the nation for hard clam sales and sixth in the nation for Eastern oyster sales (Florida Department of Agriculture and Consumer Services (FDACS), 2025a; USDA National Agricultural Statistics Service (USDA-NASS), 2019). Florida's bivalve shellfish aquaculture industry was valued at \$15.5M for total production in 2018, with 92% of sales dominated by hard clam production and 8% by oyster production (Botta et al., 2023; Florida Department of Agriculture and Consumer Services (FDACS), 2025a); this value is a marked increase from 2012, where the industry was valued at \$11.9M and hard clam production comprised 98% of total sales (Florida Department of Agriculture and Consumer Services (FDACS), 2025a). There were 854 commercial leases (437 hard clam, 197 oyster, and 199 combined) that were in use among 336 farms during 2023 (Florida Department of Agriculture and Consumer Services (FDACS), 2025a). The hard clam industry supported over 500 jobs in 2012 (Adams et al., 2014). Like the broader shellfish industry, labor estimates in Florida's shellfish aquaculture sectors are difficult to quantify.

Florida's Levy and Dixie counties implemented an aquaculture retraining program, structured similar to a previous retraining program in Apalachicola, due to the disease-collapsed wild oyster fishery

(Sturmer, 2022, slides 2-12; Weeks and Sturmer, 1996). Students received a 2-acre lease upon program completion, facilitating the first aquaculture leasing grounds on Florida's west coast. The University of Florida and Tallahassee Community College, through the Wakulla Environmental Institute, have developed and deployed shellfish aquaculture training programs to facilitate the growth of labor supply in the aquaculture sector. Additionally, hard clam growers in Cedar Key, a small island city on the west coast of Florida, received a 13-month Dislocated Workers Grant, granted through the US Department of Labor and administered through the local workforce development board, which provided over \$11M in wages to 170 people for temporary employment in the industry to clean up clam lease sites and to replant clams after loss due to destructive hurricanes (L. Sturmer, personal communication, July 8, 2025). Lemoine et al. (2025) suggests that programs and policies in Florida are needed to facilitate livelihood diversification for fishers and workers outside the industry, while accounting for socio-cultural facets, to continue expansion of US shellfish aquaculture. Florida's shellfish aquaculture industry and the communities that depend upon it face additional challenges related to social perceptions, production costs, markets and consumer demand, permitting and regulations, intensifying storms (e.g., hurricanes), water closures, repeated unexplained mortality events, and environmental stressors (Camp et al., 2020; Lorenzen et al., 2017; Sturmer et al., 2020).

2.2. Participant selection

Participants were identified through a combination of purposive sampling (participants selected based on research criteria) and snowball sampling (potential respondents referred by participants). This approach allowed for a diverse sample in terms of employment status, geographic location, scale of operation, and criteria relevant to the research question. Virginia shellfish growers were selected from a 2023 Virginia shellfish grower database that was provided by the Virginia Marine Resource Commission (VMRC). The overall list was reviewed by project team members familiar with the industry to allow for a representative range of product culture, scale of operation, and labor structure. Likewise, Florida shellfish growers were sampled from a list of leaseholders and individual operations were recruited based on the research team's familiarity with farm practices. Participants were also asked to recommend others who might be interested and/or able to provide a different viewpoint on the topic. This approach allowed for subsequent interviews with participants recommended by shellfish growers who were interviewed in this study but may not have been identified through the initial leaseholder list. The snowball approach was critical for contacting employees of these operations, as opposed to owners or leaseholders, as the employees cannot be identified through a leaseholder list and typically were reached through the employer. Employees were not interviewed at every operation. Participant recruitment, along with all other aspects of human subjects research in this project was approved by the Protection of Human Subjects Committee (PHSC; now the Institutional Review Board) at William & Mary (PHSC-2024-09-02-172-5-amscheld).

2.3. Data collection

Semi-structured interviews and participant observation were conducted with employers and employees of Eastern oyster farms, hard clam farms, and combination farms (producing both oysters and hard clams) between August 2024 and February 2025. Participants were interviewed based on individual availability and willingness to participate in the study.

2.3.1. Participant observation

Participant observation is a technique that allows the researcher to be involved within the research setting to obtain a deeper understanding of the cultural experiences and community practices (Schensul et al.,

1999). This technique was described by Schensul et al. (1999) as the "process of learning through exposure to or involvement in the day-to-day or routine activities of participants in the research setting". Participant observation was practiced in this project and occurred in a variety of settings, such as working with participants on their boat and at their facilities, and spending time with participants over meals. Including participant observation in this study provided richer context for interview responses and allowed for comprehensive understanding and familiarity of the aquaculture industry and the associated communities, but did not generate a dataset for analysis.

2.3.2. Semi-structured interviews

Semi-structured interviews were conducted utilizing a set of pre-determined questions. This interview style allows for question flexibility, in terms of order and structure, and provides the interviewer the opportunity to ask the participant follow-up questions that may be insightful for the broader research question (Bernard, 1994). Furthermore, open-ended questions avoid "yes" or "no" responses and allow for descriptive responses through theme exploration (Bernard, 1994). The predetermined set of interview questions acted as a guide to assess employer and employee perspectives on labor in Virginia and Florida's Eastern oyster and hard clam aquaculture industries. An interview guide was developed with questions specific to either the employee or the employer, available in the Supplemental Materials (Table S1). For example, an employer may be asked, "How do you recruit employees?" where an employee may be asked, "How did you hear about this job?". Themes were defined and included in the interview guide as: "Labor availability, recruiting, and retention", "Working conditions", "Job satisfaction", "Stressors on labor productivity and resilience", "Technology to substitute for or reduce labor needs", and "Growth in the aquaculture sector".

Once growers were identified, participants were contacted via email, phone, or social media and were invited to participate in the study. Interviews were either conducted in-person ($n = 46$), over the phone ($n = 4$), or via Zoom ($n = 2$) and typically were 30 min or less per individual. Participants were invited to follow up with anything that they did not feel comfortable sharing at the time or perhaps thought of later. With participant approval, the interview was audio recorded using a handheld recorder to capture descriptive information and to allow for active engagement between the interviewer and the participant. If the participant opted out of audio recording, the interview was conducted as a team with one member taking detailed notes.

2.4. Data analysis

Interview recordings were uploaded and transcribed using Otter.ai (Otter.ai, 2024). This software program translates audio files into text that can be converted and exported as individual word documents or PDFs. Otter transcriptions were checked for accuracy before exporting files for data analysis. Audio files were deleted once accurate files were exported. Interview transcripts were analyzed using MAXQDA (VERBI Software, 2021), a qualitative data analysis software that enables text data organization, visualization, and analysis. Transcripts were coded using a combination of deductive and inductive methods to identify emerging themes related to labor availability, working conditions, job satisfaction, industry stressors, views on labor reducing technologies, and industry growth. Deductive coding utilizes a predetermined list of themes that was developed prior to the data analysis and is based on previous research (Fereday and Muir-Cochrane, 2006); whereas inductive coding constructs newly identified themes during the secondary analysis (Fereday and Muir-Cochrane, 2006). Transcripts were first coded through the deductive approach, and the codebook was refined through the inductive approach to ensure that all themes and codes were complete and relevant to the entire dataset. Based on the interview guide, six main themes were identified and described for the initial analysis to investigate labor demands in Virginia and Florida's oyster

and hard clam industries, including: labor availability, working conditions, job satisfaction, stressors, technology substitution, and industry direction (Table S2). Sub-themes were identified under the initial main themes (Table S2).

Descriptive and inferential statistics were used for analyses in this study. Descriptive statistics were used among the entire data set, while inferential statistics were used to explore participant perception related to stressors and industry growth, separately. A Cochran's Q test was used to identify statistical differences among stressors and industry growth topics, which were identified in the inductive code analysis. This test was chosen given the dichotomous response variable (e.g., yes/no, true/false) and because repeated measures with paired responses were present (Mangiafico, 2016). Participant responses were coded as binary where 1 indicated a "yes" response and 0 indicated a "no" response to create proportions of successes, similar to the methods used in Mangiafico (2016). A Cochran's Q post-hoc test was then used to identify which specific groups were significantly different from one another (Mangiafico, 2016). To test for mean differences within groups, an analysis of variance (ANOVA) was also used for topics of stressors and industry growth. A Tukey's Honestly Significant Difference (HSD) test was used as a post-hoc, when ANOVAs were significant, to identify specific group differences. An alpha of 0.05 was used as a threshold for statistical significance for all tests. R statistical software was used for statistical data analyses (R Core Team, 2019).

3. Results

We conducted 52 interviews in Florida ($n = 24$) and Virginia ($n = 28$) across 37 shellfish farms. Operation size ranged from 1 to 200 employees with annual production fluctuating from hundreds to hundreds of thousands of bushels. For the purpose of this study, farms that maintained 10 or fewer full-time, part-time, and unpaid employees were considered small to medium in size ($n = 27$ farms), and farms with 11 or more employees were considered large in size ($n = 10$ farms). Employers ($n = 43$) and employees ($n = 9$) of shellfish aquaculture farms were interviewed for this study. Employers were defined as individuals who own and/or manage the farm with full or partial authority over the business and who are specifically involved in supervising and/or hiring employees. Participants were further categorized by their work demographics, including state location (e.g., Florida, Virginia), operation size (e.g., small/medium, large), and product grown (e.g., clam, oyster, combo; Table 1). All participants of this study utilize shellfish aquaculture as a main source of income, albeit not necessarily their only source of income. Among the operations visited, 8 of 37 farms (6 Virginia farms and 2 Florida farms) were vertically integrated, meaning that they own a hatchery and rear seed from start to finish. It is important to note that while all participants were either oyster and/or hard clam growers, a subset of growers were also involved in other aspects of the industry, such as seed and product sales, research and development, and ecotourism.

There were 46 participants who provided voluntary demographics information. Most participants identified as male ($n = 35$), with a

smaller number who identified as female ($n = 10$), and one participant did not provide gender identification. Participants represented a range of ages: 18–30 ($n = 9$), 31–40 ($n = 11$), 41–50 ($n = 8$), 51–60 ($n = 9$), and 61 or older ($n = 8$). Almost all participants identified their race as White ($n = 41$); other race and ethnicity descriptors were shared by fewer than three individuals and are not presented here to preserve anonymity.

The following results are strictly based on information provided by participants during the interviews. For context, and when useful, a participant quote is included to reflect an aspect of the interview theme, though the quote may not represent the complete array of viewpoints shared on the subject. Quotes are from multiple participants, each quote from a unique participant. Due to the complexity of topics discussed by participants, information is summarized when necessary.

3.1. Labor availability

Employers were strategic in the number of employees hired at their operation and typically followed a business plan for economic growth. Costs were a considerable factor for business growth (see participant quote below). Full-time, part-time, salaried, non-salaried, volunteer, family, friends, and migrant workers were used by employers. Smaller farms maintained roughly one to five employees, whereas larger operations, while limited to a few, can reach over one-hundred employees. Paid full-time and part-time employees were common, though smaller operations were more likely than larger operations to utilize unpaid workers over paid workers. There were 7 farms (19% of total farms visited) that utilized unpaid laborers at their business, including family (e.g., spouses, children) and volunteers. Some employers stated that they do not draw a salary from their operation, and instead only pay their employees, which occurred at 7 farms; though, it is assumed that these employers receive excess returns and profits from the business as an income source.

Interviewer: "How often were you hiring at your business?"

Virginia Oyster Grower: "...I guess the reason I haven't hired any other workforce or expanded to get a bigger workforce is because of minimum wage and salary requirements, and because I have not wanted to do H2-B visa[s]."

At least 7 farms utilized or are in the process of enrolling in the H2-A or H2-B visa migrant workers program, and one participant expressed interest in the visa program as a future labor strategy. All operations utilizing the program were in Virginia. Employers enrolled in a migrant workers program suggested that overall labor efficiency and product output increased with the use of migrant labor; however, employers emphasized that the program was costly and time-consuming. The visa program was often utilized by larger operations, but in one case, a smaller farm was also taking part.

Operations used a diverse mix of hiring methods for recruiting employees, including word of mouth ($n = 25$), job postings ($n = 21$), workforce development and educational programs ($n = 9$), and the unemployment office ($n = 1$). Only one operation did not advertise for employees. Hiring employees via word of mouth was noted as the most efficient and effective method by employers. The number of times that employers hire throughout the year varied by operation, although several employers mentioned that they were consistently hiring due to high employee turnover (see participant quote below). Employees interviewed in this study were in search of a job and found their current position via word of mouth, job postings, or through workforce development programs. When job searching, employees did not find it challenging to find and/or keep work within the shellfish aquaculture industry.

Interviewer: "How do you recruit employees?"

Florida Clam Farmer: "It's kind of ironic. It seems like every time we lose a guy, another guy shows up and then, I mean, right now, it's hard to find him [an employee], because I could use a couple [employees]. I'm losing a guy to college, and I really could use a guy, and I'm just hoping a guy shows up in the next month or so."

Table 1

Summary characteristics of participants by state, operation size, and product produced.

Participants by State	Operation Size		Product		
	Small/ Med. ($n = 40$)	Large ($n = 12$)	Clam ($n = 9$)	Oyster ($n = 35$)	Combo ($n = 8$)
Florida ($n = 24$)	21 (16, 5) *	3 (3, 0) *	6 (5, 1) *	15 (11, 4) *	3 (3, 0) *
Virginia ($n = 28$)	19 (16, 3) *	9 (8, 1) *	3 (3, 0) *	20 (18, 2) *	5 (3, 2) *

* Refers to the number of employers and employees: total participants (employers, employees).

Almost half of all participants ($n = 23$) mentioned poor reliability of employees among shellfish aquaculture farms, suggesting that it can be difficult to find reliable workers within the industry; nevertheless, some employers mentioned the tendency toward reliable employees and do not have a challenge with retention ($n = 11$). The employees' willingness to work (e.g., work ethic) was a main factor suggested by employers that impacts employee retention. Employers suggest that employees are exiting the industry often, although there is variability depending on the business (e.g., from one day to years). Typically, employees exit the industry for new job opportunities (e.g., better wages, career advancement) and/or disinterest in working at shellfish farms due to challenging working conditions (e.g., physical labor, environmental conditions). An oyster farm employer suggested that employee turnover can be an advantage for the employees, as the grower stated that their business acts as a steppingstone for employees as they search for alternative career opportunities (see participant quote below).

Interviewer: *"Was it difficult to maintain reliable workers at your business?"*

Virginia Oyster Grower: *"Most of them don't go into the oyster field... they become electricians, stuff like that. So, we're kind of like a steppingstone. We've had a lot of young kids that get out of college and kind of don't know what to do...so they work here for a while..."*

Retention practices at farms were discussed to gain a deeper understanding of what benefits, if any, are being offered to employees to enhance retention rates. Health benefit packages, such as dental and medical, were provided by select businesses, though several businesses were interested in providing health benefits to employees with future business growth. Other benefits provided by employers revolved around personal wellbeing (e.g., yoga breaks, lunch, personal protective equipment, housing), team bonding events (e.g., bowling, going to the movies), professional development opportunities (e.g., boating license), and employer-employee trust at the workplace (e.g., allowing employees to oversee work). Some retention practices had unexpected outcomes; for example, after an increase in hourly rate, employees became less productive and reduced their work hours (see quote below). Growers also suggested the retention practice of switching the pay structure (e.g., hourly to salary), which led to employees working less in some cases. Generally, the benefits provided by the business to the employee depended on the scale and structure of the operation, as larger farms were able to provide more money toward sought-after benefits (e.g., health benefits, salary pay) that smaller farms could not afford.

Employees provided their thoughts on what benefits would hypothetically retain them at the workplace; examples included sustainable pay, health insurance, paid holidays and sick leave, promotion/advancement in the workplace, professional development opportunities, and a positive work environment. Maintaining a livable pay wage and finding affordable housing were noted as key challenges of employees.

Interviewer: *"Have you tried anything to ensure retention at your business?"*

Florida Clam Farmer: *"I'm paying you more because you do a good job... that's incentive to better yourself. 'Nope, that's all I need. I'm good now I'll work 30' ... then I gotta hire someone else, because now I'm 10 hours short and it still goes the same. So, you know, I'm not big on giving raises. I just start them off well and I see what you can do."*

3.2. Working conditions

Working conditions varied by operation, including hours worked, environment, and labor requirements. Such conditions can be dependent on location, operation type, and species grown. For example, there are vast differences in the work demands needed at a hatchery, nursery, and during the final grow out stage. Each participant described tasks by their workday and workweek and, while processes were similar (e.g., harvesting, tumbling, etc.), each operation worked differently. Employers and employees in this study were typically working five to six days a week. On average, workers spent 8 to 10 hours per day at their

job, totaling to roughly 40 to 50 hours per week; daily labor hours were dependent on the number of available employees, seasonality, farm upkeep, and harvest needs. Other variable factors that were noted to directly impact working conditions included weather, labor availability, and sales.

Interviewer: *"What does a work week look like?"*

Florida Oyster Grower: *"So the average work week, no one knows!"*

Labor requirements varied depending on the time of the year. Participants discussed the seasonality of their work, including peak and off seasons, and how this seasonality impacted their labor demands. Labor seasonality was most prominent among the Virginia growers compared to the Florida growers, as only one operation mentioned that they were busy year-round. Florida and Virginia growers, including both hard clam and oyster operations, experienced larger sales and increased labor needs around the holidays due to increased consumer demand. Additionally, drivers of labor fluctuations mentioned by participants include market and consumer demands, husbandry needs, and seasonality (e.g., summer vs winter).

Interviewer: *"Does the number of employees that you need change throughout the year?"*

Virginia Oyster Grower: *"Yeah, we would like to have [extra employees] during the spring and summer months ... that's when we're planting seed, trying to do all the things that you have to do on the farm."*

3.3. Job satisfaction

Almost all participants expressed that they were happy in their current job position ($n = 49$). Participants were asked why they do their job and what drew them to their current position as an oyster and/or hard clam grower (see participant quote below). Several growers stated a passion for working on the water and noted other nonmaterial benefits associated with their work. For example, continuing a family legacy and growing or starting a family business have kept many growers in the industry. Several growers were introduced to the industry through family and/or friends, with others through education and workforce development experiences. Beyond lifestyle, the career choice allows growers to work directly with nature, in what was mostly expressed as a fun, yet challenging environment. The challenge of meeting market demands and the strenuous labor that comes with working on the water provides a sense of fulfillment among many participants, along with learning new skills, finding new opportunities, developing relationships, and the fruits of labor directly resulting from dedication to the job. For several employers, the flexibility of being their own boss was mentioned as an advantage, though the administration of running a successful business can be difficult. For employees, the importance of a positive work environment was significant for job satisfaction. Employees also suggested that the feeling of trust and personal responsibility at the workplace elevates their overall performance and was considered a necessity for career advancement. When employees were asked if they hoped for opportunities of promotion or advancement, 44% of employees interviewed ($n = 4$) were interested in higher roles such as managerial positions.

Interviewer: *"Why do you do your job?"*

Virginia Oyster Grower: *"Because I love it. I don't know. I get satisfaction out of growing something myself and keeping up with it and maintaining it... it only takes a couple weeks for you to fall behind ... but when you're on top of things, you can produce really nice oysters."*

Participants also shared the parts of their job that they do not enjoy. Many growers mentioned that the work was very time consuming and that the work environment is challenging, more specifically highlighting that the labor can be emotionally and physically exhausting and creates wear and tear of the body from daily work activities. The unpredictability of the job and stress of the unknown (e.g., related to costs and business operation) was a topic of concern. Participants also mentioned

the repetitive nature of the job, noting that tasks are not intellectually challenging and can lead to a daily burnout of consistent work. Employers mentioned that finding and hiring reliable employees is a constant challenge and makes it difficult to enjoy the full aspects of their job, mostly due to the stress of ensuring that there are enough employees to complete the workload. Employees mentioned that poor wages and a lack of benefits make it difficult to stay at their job, especially when a higher wage and greater benefits can be earned at less demanding jobs. While these non-material benefits are important to maintain, some growers suggested that they want a different way of living for their children and grandchildren, due to the difficult working conditions of shellfish aquaculture, and push them to explore academic opportunities and alternative career choices.

Interviewer: "Are you happy in your position?"

Florida Oyster Grower: "It's very hard to keep a positive, happy environment, because it's dirty, hot, during the summer, heavy work, and during the winter, it's really freaking cold, there's been ice on the boat."

3.4. Stressors on labor productivity and resilience

Participants were asked about general challenges that impact their operation. Challenges discussed by participants were typically related to their business or the environment, which were later labeled as 'Business Stressors' and 'Environmental Stressors' in the codebook, and were split into subcodes (Table S2, Table S3). Business stressors were coded ($n = 428$) and were split into seven main categories: business logistics, finances, labor, regulations and permitting, risks, and social acceptability.

Similarly, environmental stressors were coded ($n = 148$) into five main categories: biofouling, environmentally linked product mortality, water quality, and weather conditions. Subcodes, such as labor and product mortality, were further split to examine specific differences in the groupings (Table S3).

Business and environmental stressors negatively impacted labor productivity across farms. Almost all participants ($n = 50$) mentioned business stressors and a significant number of participants ($n = 42$) mentioned environmental stressors that impacted their operation. Oyster growers ($n = 33$), hard clam growers ($n = 9$), and combination growers ($n = 8$) mentioned business stressors; similarly, environmental stressors were also noted by oyster growers ($n = 25$), hard clam growers ($n = 9$), and combination growers ($n = 8$). For Virginia growers, 27 participants mentioned business stressors, while 20 mentioned environmental stressors. Likewise, 23 Florida growers mentioned business stressors, and 22 mentioned environmental stressors. An ANOVA showed statistical differences in means among business stressors and environmental stressors, separately, for all growers ($p < 0.001$; $p < 0.001$), oyster growers ($p < 0.001$; $p < 0.001$), hard clam growers ($p = 0.05$; $p < 0.01$), combination growers ($p < 0.01$; $p < 0.05$), Virginia growers ($p < 0.001$; $p < 0.05$), and Florida growers ($p < 0.001$; $p < 0.001$). The Tukey's HSD post-hoc test showed statistical differences in business stressors for oyster growers, Virginia growers and Florida growers (Fig. S1) and for all growers combined (Fig. 1); along with statistical differences in environmental stressors for oyster growers, hard clam growers, combination growers, Virginia growers, Florida growers, and all growers combined (Fig. S2).

Cochran's Q tests suggested that differences existed in at least two response variables that were compared within business stressors,

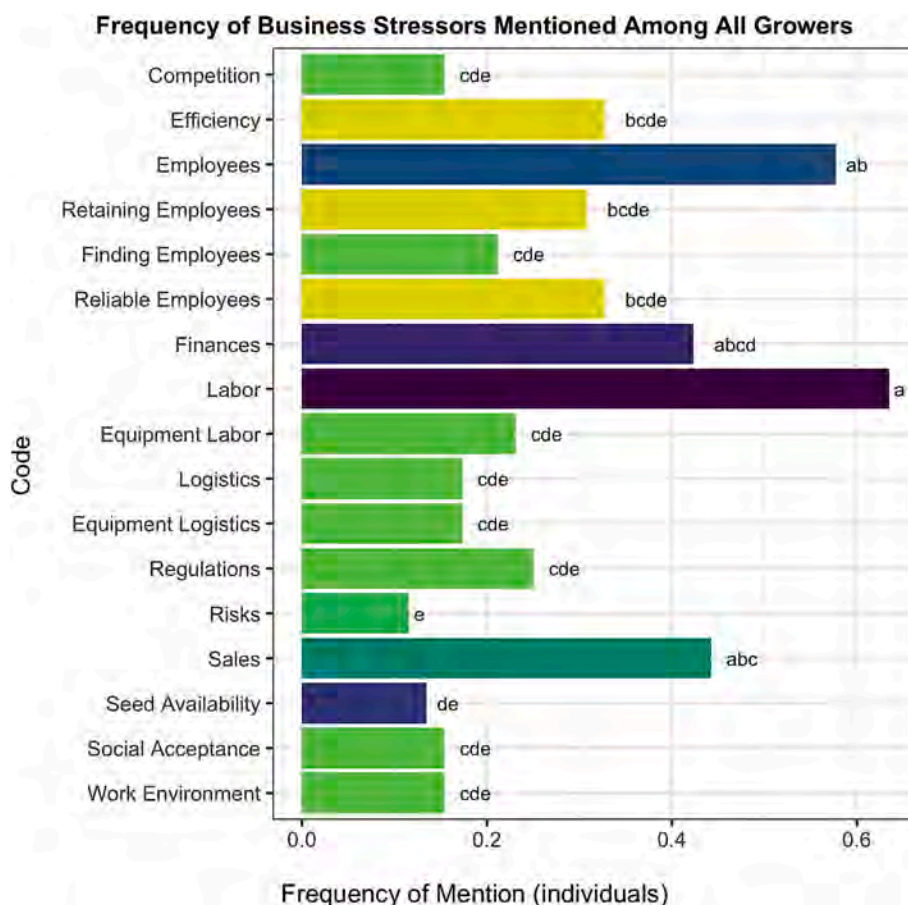


Fig. 1. Fifty participants (including oyster growers, hard clam growers, combination growers, Virginia growers, and Florida growers) mentioned business stressors. Differences in perceived business stressors were evident. If the pairwise comparisons do not share the same letter (e.g. "a" vs "b"), then there is a significant difference in the compared means. Letter groupings are organized by color. Code descriptions and examples are included in Table S3.

suggesting heterogeneity, for all growers ($p < 0.001$), oyster growers ($p < 0.001$), hard clam growers ($p = 0.05$), combination growers ($p < 0.01$), and growers located in Virginia ($p < 0.001$) and Florida ($p < 0.001$). Similarly, at least two environmental stressor response variables were heterogeneous for all growers ($p < 0.001$), including oyster growers ($p < 0.001$), hard clam growers ($p < 0.01$), combination growers ($p < 0.05$) and Virginia ($p < 0.01$) and Florida growers ($p < 0.001$). To further investigate which response variables differed from each other, Cochran's Q post-hoc was utilized. The post-hoc tests showed statistical significance for oyster growers and Virginia growers who mentioned business stressors (Table S5), with labor as a common stressor mentioned along with other stressors. The post-hoc tests also showed statistical significance for oyster growers, and Florida growers who mentioned environmental stressors, with storms as an overarching concern (Table S6). The post-hoc tests did not show significant differences among pairs for hard clam growers, combination growers, and Florida growers who mentioned business stressors, or for combination growers and Virginia growers who mentioned environmental stressors, though the Cochran's test suggested significance. This suggests a difference between groups, but the differences across response variables are not strong enough to be statistically significant, possibly due to multiple comparisons, differences in statistical power of the tests, and/or effect size.

3.5. Use of technology to substitute or reduce labor needs

Over half of the participants ($n = 33$) suggested interest in a software tool for tracking labor productivity and efficiency at their business (see participant quote below). Most participants were not using a software tool for farm management, mostly due to barriers such as cost, ineffectiveness, and user-interface.

Interviewer: "Would you be interested in using a free software tool for tracking labor hours at your farm?"

Florida Oyster Grower: "I love the idea of having a labor tracker, and... having it available, and kind of showing what we're spending so much time on because... if I find out I'm spending 40 hours a week scraping oysters... I probably need to change something in my workflow..."

Many farms were intrigued by the idea of technology reducing labor needs while increasing total product output, to create a more efficient work environment. While a large portion of participants felt that technology could be beneficial for reducing or substituting labor needs ($n = 29$), other participants felt that technology would not be beneficial for their operation ($n = 10$). Thirteen participants specifically preferred increased technology use in addition to farm workers, while 6 participants preferred traditional manual labor with limited technology usage at their operation. Cost was identified as a major barrier for expanding technology needs at operations as labor-reducing technologies can cost hundreds of thousands of dollars. The interview data showed that the decision for employers to purchase technology, to pay farmhands, or to utilize both strategies is dependent on business structure and strategy, such as operation size, associated costs, and production goals (see participant quote below). Additionally, interviewees noted a desire for technology to be tailored to farm needs and to reduce physical strain, which emphasized the need for adaptability and flexibility of tools.

Interviewer: "Are there areas of your business that could benefit from technology?"

Virginia Oyster Grower: "There's a point where having extra equipment helps, but if you don't have the manpower to use it, you're spending money on equipment you're not using."

3.6. Growth in the aquaculture industry

When asked about the industry's potential for growth, 48 of 52 participants provided their thoughts on whether the industry would grow or not and what factors could impact growth. Twenty-nine participants thought the industry would grow, 8 suggested that there is potential for growth, and 11 saw little to no growth potential in the

industry. Participants who were unsure hoped that the industry would grow and were interested in seeing it flourish. Several factors were mentioned that made it difficult for participants to lean one way or another in their decision, including market and demand (e.g., saturation, product sale price), social pushback, and changes in the environment (e.g., disease, product loss, water closures; see quote 1 below). Participant responses were graphed as frequencies to compare growth perceptions across species type (i.e., oyster, hard clam, combo), state (i.e., Virginia, Florida), and employment status (i.e., employers, employees; Fig. 2).

Participants were asked what could facilitate or stall industry growth and 50 of 52 participants provided a response. The codes 'Facilitating Factors' and 'Stalling Factors' were determined and added to the codebook and were later split into subcodes (Table S4). Participants mentioned facilitating factors related to market demand and public perception the most. Specific factors mentioned by participants that would support continued growth of the industry included sustainability of culturing oysters (compared to wild harvest), as well as increasing product demand and public perception through consumer education of the benefits of eating shellfish products. It is important to note that some growers who see growth in the industry see it for larger farms, but thought smaller, family-owned 'mom and pop' farms may be pushed out of the industry (see quote 2 below). Participant perception of factors that could stall industry growth were widespread, the greatest impediments were among the following: competition, cost, environment, labor, market demand, public perception, regulation, and business miscellaneous (i.e., more general business-related attributes and events that do not fit cleanly into other categories; e.g., the ability to maintain a "good living"). Specific challenges were noted, including repairs, damages, and product loss from storms, poor and/or unreliable insurance coverage, mass exodus of operations (due to costs, labor shortages, sales, storm damage, etc.), thin and variable profit margins among businesses, finding and receiving quality seed on time from hatcheries, market saturation, access to waterfront property, and social pushback (see quote 3 below). Additionally, a subset of Virginia growers mentioned that while they see potential for growth in the broader aquaculture industry, they do not see further growth in Virginia, due to a saturated market, stalled consumer demand, and social pushback from waterfront property owners. This is different for Florida growers where markets were less of a concern, but costs associated with operation damages and product loss from storms, harmful algal blooms, and other poor environmental conditions were thought to stall industry growth.

A Cochran's Q test suggested that differences existed between at least two response variables that were compared with positive and negative industry direction when compared jointly ($p < 0.001$) and separately ($p < 0.001$; $p < 0.001$). To further investigate which pairs differ from each other, Cochran's Q post-hoc was utilized (Table S7). An ANOVA showed significant differences in means among negative industry impacts ($p < 0.001$) and positive industry impacts ($p < 0.001$). Differences in perceived factors impacting industry growth were evident from the Tukey's HSD post-hoc test for factors that would facilitate or stall growth (Fig. 3).

Interviewer: "Do you see potential for growth in the shellfish aquaculture industry?"

1- Virginia Oyster Grower: "I do and don't. So I do think there's definitely an opportunity for growth, but I do actually worry that we're doing a bit with the oyster industry that they did with the clam industry in the, whatever that was, the 80s. It was pushed, pushed, pushed, pushed, pushed, and then the market wasn't there."

2- Florida Combination Grower: "I definitely see it for big corporations, I see it. I see them making some bank ... because it takes less labor and the reward is greater, there's less risk involved, you know?"

3 - Florida clam grower: "I don't see a lot of people wanting to do this. You know? It's a hard way of life, very demanding on your body. And the

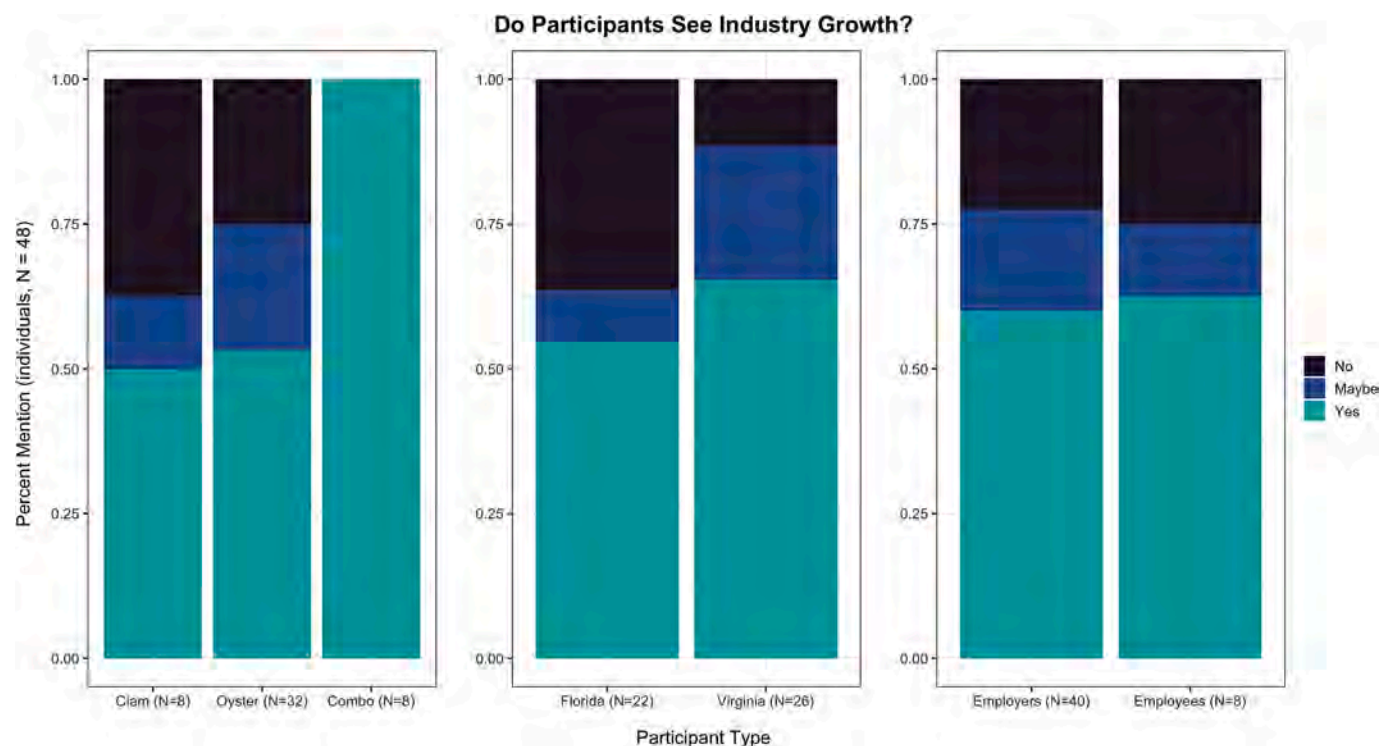


Fig. 2. Forty-eight participants discussed future industry growth, where “Yes” indicates there will be growth, “No” indicates there will not be growth, and “Maybe” indicates they are unsure of growth. Participant groups were split by species grown, state, and worker status.

weather situations, very stressful going out there after this big event, seeing all your stuff dead, pretty disheartening”

4. Discussion

4.1. Labor needs and experiences

The availability and stability of labor in Virginia and Florida's coastal communities can be limited by rural access and individual motivation to work in a labor-intensive field. Labor demands were variable by operation and seasonal labor patterns existed across the sample. Working conditions across operations differed due to location, production method, species grown, and operation scale, though some culture techniques (e.g., using a tumbler, cleaning with a pressure washer) were similar across farms. A consistent peak season relative to labor needs was not identified, which was expected due to the variable environments and work needs in the two states. Trends in labor hours throughout the year were noted but were related to farm activities. Labor seasonality was more distinctive in Virginia than Florida, though this is likely due to Virginia's pronounced seasonal changes and was vastly different for oyster and hard clam growers. While staffing shortages and employee turnover rates were frequent topics of discussion, the results do not suggest a specific pattern in which turnover rates were highest. Additionally, the results do not suggest a pattern associated with turnover rates and retention, which is likely due to the differing retention practices utilized by the businesses. Continuous training of rotating employees created a time consuming and labor-intensive challenge for employers, which made it difficult to grow their operation. Larger operations with higher production rates required larger labor demands and more employees year-round. This was expected and is similar to Cobb and Douglas' (1928) production theory, where increased labor and capital inputs furthers output; though, it should be expected that production expansion can face a gradual decrease in rate of return. Romer (1990) further emphasized that labor and capital shape productivity, but not without advancements in policy and/or

improvements in technology.

Consistent employee turnover has raised questions about employee motivation to enter, remain in, or exit the industry, and how working conditions, job satisfaction, and additional factors may impact that motivation. The results showed that entry pathways to the industry are diverse, including family businesses and training programs. The decision to enter, stay in, or exit the industry, however, is up to individual motivation. Almost every participant interviewed in this study suggested satisfaction with their current career in shellfish aquaculture; though, we must acknowledge potential sample bias given employee interviews were voluntary and conducted at the suggestion of employers, and we did not recruit prior employees as participants. Employer and employee satisfaction were similar but differed based on worker duties; for example, an employer may find satisfaction in being their own boss, whereas an employee may feel satisfied in learning new career skills. Participants expressed several challenges that made daily work tasks difficult, but many felt rewarded through benefits of work effort and successfully growing shellfish. The analysis indicated that positive job satisfaction correlated with the worker's decision to maintain employment at the workplace, which was expected. For example, a positive work environment, competitive pay, and health benefits add to worker satisfaction, but strenuous working conditions, unpredictability, and the repetitive nature of the job made it challenging for workers to maintain satisfaction. Broader recommendations for employers should be developed to enhance job satisfaction and employee retention to reduce turnover at the workplace; like workplace culture training, rewarding employees for good work, and providing flexibility for work-life balance. It should be acknowledged that some employee turnover is inevitable given labor seasonality.

A safe work environment has been found to increase job satisfaction and ensure workforce stability, along with professional development and training opportunities for employees (Himawan and Munizu, 2025; Santhanam-Martin et al., 2024). Though worker safety was not a prominent topic of discussion in this research, we found that employees were interested in career advancement opportunities to further advance

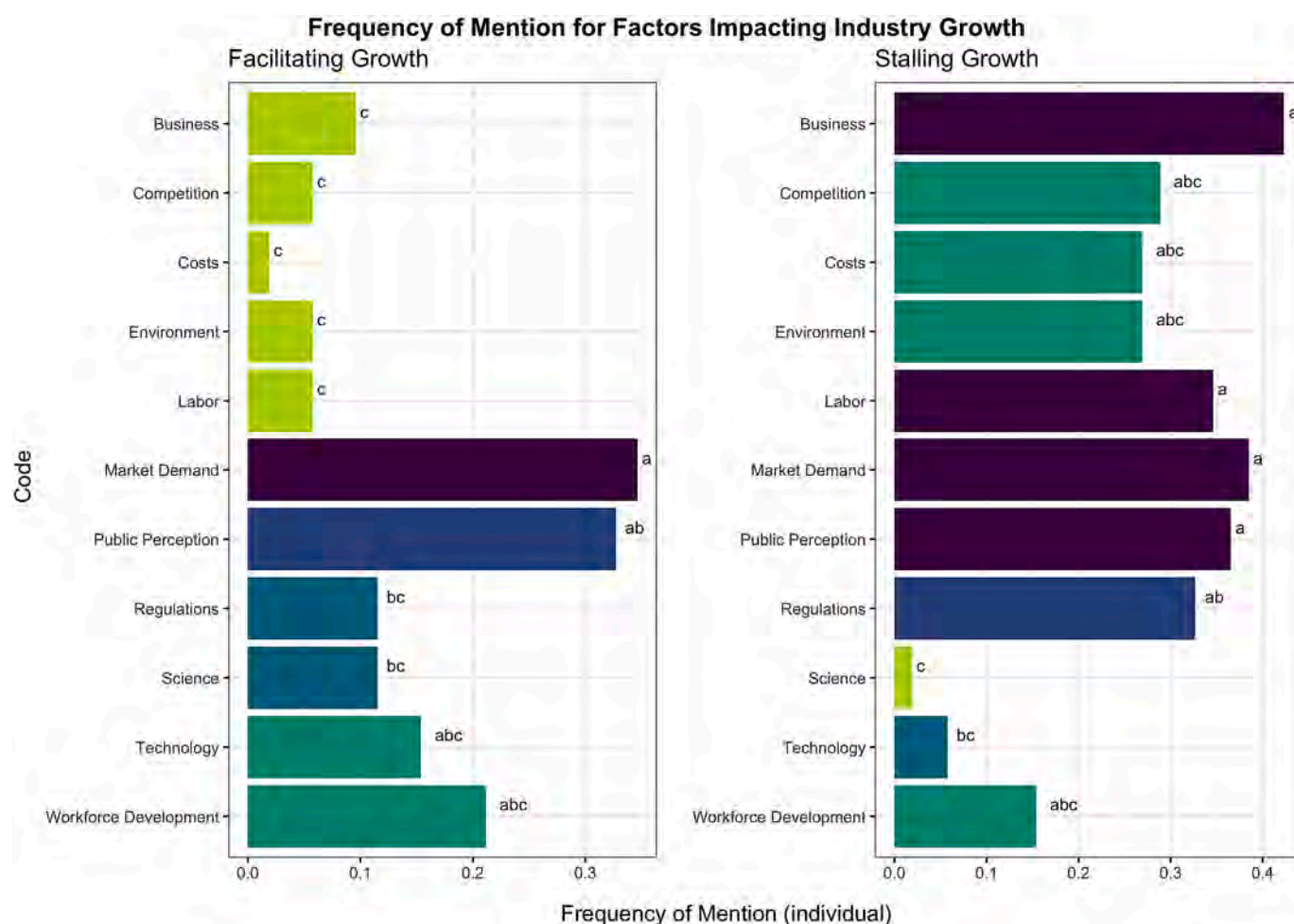


Fig. 3. Fifty participants discussed factors that could facilitate or stall future industry growth. Differences in perceived factors were evident for both growth facilitators and stallers. If the pairwise comparisons do not share the same letter (e.g. “a” vs “b”), then there is a significant difference in the compared means. Letter groupings are organized by color. Code descriptions and examples are included in Table S4.

themselves in the industry, such as through apprenticeship training. Career promotion opportunities in shellfish aquaculture can be limited as there are three primary career categories in the sector, where workers typically start as a farm hand (technical or non-technical) and can be promoted to a crew chief (like an assistant manager) or a manager (Gulf of Maine Research Institute, 2021). Almost half of the employees who were interviewed (44%) hoped for promotion or advancement and, in some cases, employers discussed potential transitions of managers to farm ownership; this was farm-specific and was more common for small family-run farms. It is possible that employment periods (e.g., short term, long term), increased managerial responsibility (e.g., inheriting the business), and other related factors impacted whether an employee was interested in promotional advancement. Promotion can happen quickly for workers depending on their skillset, which can be refined through experience developed from working on a farm or from education offered by technical and vocational schools and colleges (Gulf of Maine Research Institute, 2021); these opportunities, however, are limited and are not offered nation-wide. Additionally, high-impact retention practices (e.g., health benefits, competitive pay) may be considered of greater importance in an employee's decision to retain work in aquaculture. We found similar results to the findings of Himawan and Munizu (2025), where a relationship was distinguished between employee engagement and worker retention at seaweed farms, and industry exit was associated with key factors such as working conditions and financial compensation. Several operations that participated in this study recognized the need for sought-after retention practices to

maintain employees at the business, although whether the employer could provide desired benefits, or any benefits at all, depended on the scale and the structure of the business. Larger businesses were more likely to provide benefits sought after by employees. This result is similar to Green et al. (2023), where larger farms were more inclined to incentivize employees for recruitment and retention purposes, whereas smaller farms delayed or avoided expanding their operation due to existing labor shortages. Large scale operations may be advantaged, compared to smaller scale operations, by having greater ability to substitute across resources and production inputs.

A variety of solutions to managing labor demands for production efficiency were discussed; though, it is important to note that all solutions may not be economically feasible for all growers. A subset of Virginia growers enrolled in the H2-A and H2-B visa programs as a solution to limited labor availability, though recent proposed legislation for stricter enforcement of the H2-B visa program could limit enrollment (Restriction on Entry of Certain Nonimmigrant Workers, 2025). This option may be more common for larger operations due to the high costs associated with housing and paying migrant workers, and the strenuous administrative burdens required for program entrance. Many growers utilizing the visa program emphasized a significant increase in labor productivity and total product output at their farm, in some instances even with fewer workers, compared to past experiences using local labor. In contrast, some employers pride themselves in hiring local labor at their farm to aid in community development and to bestow generational knowledge to rising (typically younger) shellfish growers.

Growers who had shifted to visa programs also shared that interest but acknowledged that switch was made out of necessity after struggling to find employees.

Participants were interested in integrating technologies in their business, like advanced gear methods, cost-effective equipment, and simple user-interface apps, to enhance production efficiency and increase total output. The decision for employers to purchase technology, to pay farmhands, or to utilize both for efficiency is dependent on production and business plans, as cost was identified as a major barrier for integrating technology at the business; however, it is important to note that none of the participants suggested that they prefer to mechanize and/or automate their operation over providing jobs to current or future employees. This result aligns with previous research, where technology characteristics, economic factors, farm characteristics, sociodemographic factors, and institutional factors play a significant role in technology adoption at aquaculture operations (Kumar et al., 2018). Mechanization could improve job sustainability by reducing the physical strain that farmers often face due to strenuous working conditions, as described by growers in this study. It is important to consider that technologies could be used at farms to mitigate strain without reducing the workforce. Studies have linked the evolution of labor productivity, technological advances, and economic restructuring globally (Ayed Mouelhi and Ghazali, 2020; Dekle, 2020), and technology advances and challenges have, more recently, been investigated for transforming the shellfish and finfish aquaculture industry through automation and mechanization (Chowdhury et al., 2025; Shenghu et al., 2025). For example, an autonomous vehicle in oyster aquaculture, specifically for reducing manual labor to flip oyster bags, has been developed to improve productivity at shellfish farms (Kornberg et al., 2021). Another example can be recognized in a subset of Oregon shellfish growers, who invested time and finances for switching, modifying, and/or improving gear, equipment, and culture techniques to combat supply chain stressors, avoid product mortality, reduce labor needs, and rear higher quality product (Green et al., 2023).

Mechanization considerations are important for informing discussions of future industry growth, such as whether technologies should be used to mitigate overexertion, reduce labor needs, or both. It is crucial to consider the potential loss of non-material benefits and local and ecological knowledge if the number of jobs are reduced with mechanization; few humans needed and working could lead to less knowledge passed on from generational shellfish farmers. This knowledge has been found crucial for studying ecology and improving shellfisheries management around the globe (Gibbs et al., 2024; Murray et al., 2006; Silvano and Valbo-Jørgensen, 2008). While increased technology use could potentially reduce labor needs, technology could augment productivity, expand total product output, reduce worker risks (e.g., injuries), and increase job opportunities in the industry under certain conditions (e.g., newly created roles).

4.2. Industry direction

While a variety of workforce related challenges were noted in this study, environmental stressors were also of high concern. Growers suggested that an unpredictable environment can be emotionally and physically challenging for workers. Storms and weather conditions were frequently mentioned by growers, particularly Florida clam growers. It is unsurprising that Florida growers more often mentioned environmental stressors based on storm and hurricane history, and their destructive impact on the landscape and the surrounding fishing and aquaculture industries (Buck, 2005; Lorenzen et al., 2017). Poor water quality and product mortality were of concern to growers for operational success, which can be directly related to complex confounding drivers like frequent storm events, intensifying algal blooms, and temperature increases (Lorenzen et al., 2017). Labor needs can intensify due to additional preparations for, or work delays caused by, damaging environmental incidents. Such stressors can reduce production output,

worker morale, and retention rates due to the uncertainty of the job, while potentially increasing physical labor needs. Green et al. (2023) found that Oregon shellfish growers were most concerned with environmental stressors, followed by regulatory and economic stressors. This result differs from the findings of this study, where business stressors were largely discussed more than environmental stressors, however, this could be attributed to the overarching research focus on labor. It should be noted that differences in frequency across business stressors were found to be marginally significant (in the ANOVA test and the Cochran's Q test) for hard clam growers, suggesting that differences in perceived business stressors were of lesser concern for clam growers.

Increased and improved public perception outside of the shellfish aquaculture industry was noted as a key facilitator for industry growth, as the ongoing acceptance of a business, also known as social license to operate, has been a barrier to industry expansion (Brugere et al., 2023). Growers emphasized the need for increased opportunity to enhance public perception (e.g., talking with the public) about aquaculture to further consumer comfort with eating and cooking shellfish products, specifically for growing the market. Participants provided ideas for increasing public awareness, such as through social media, product advertisements, and the act of being a good neighbor. Increasing conflicts over the use of public resources and aquaculture expansion have led to a growing body of literature on the public perceptions of aquaculture (D'Anna and Murray, 2015; Mazur and Curtis, 2008). Mazur and Curtis (2008) encapsulate some of these ideas and provide others as well, including transparency of aquaculture decisions, regulations to minimize environmental impacts, improved communication among stakeholders, and enhanced industry capacity for environmental management and community engagement. Similar multifaceted strategies have been identified in Budhathoki et al. (2024) and Pei et al. (2025). Furthermore, Thomas et al. (2017) found that high-awareness groups were more supportive of kelp aquaculture, compared to low and medium-awareness groups. As the industry continues to grow, advanced technology use and aquaculture expansion to new locations and species must be considered for shellfish aquaculture management and building trust in surrounding communities (D'Anna and Murray, 2015).

Market demands were a large concern in this study, specifically market capacity and increased competition. Some oyster growers were apprehensive about industry growth due to limited market demand, with some Virginia growers concerned about market saturation, though this was not a major concern for hard clam growers. Gonçalves et al. (2024) estimated that seafood demand in Virginia accounted for 41.6% of total seafood landings based on per capita consumption. The results of this study indicate that fluctuating markets and consumer demands could influence how operations invest in labor-saving or replacing technologies. For example, it may be more feasible for an employer to hire farmhands based on short-term expectations of output and production needs rather than to invest in labor-reducing technologies that require significant financing under uncertain market conditions. For others, investing in technologies that reduce physical work strain and enhance overall production to meet demands could fit with long-term expectations of business growth. Increased seafood consumption and growing markets could aid in workforce and industry expansion. Effective branding has been concluded as a method for increasing consumer awareness and attention to Florida grown oysters (Botta et al., 2023), and seafood marketing programs in Virginia (e.g., Virginia's Marine Products Board) and Florida (e.g., "Fresh from Florida") are used to promote fresh and local aquaculture products to expand domestic and foreign seafood sales (Florida Department of Agriculture and Consumer Services (FDACS), 2025b; Virginia Marine Products Board, 2025). Furthermore, market demand can be driven by public perception. Misalignment of market demands and public perception can occur when controversy about the product (e.g., quality, price, production, etc.) exists. Effective marketing strategies to enforce positive perception in the seafood sector could enhance product visibility, increase availability, and expand sales; though, various

production factors, like reducing production costs and incorporating green farming techniques, must be addressed (Azra et al., 2021). It is important to consider how growing demands, consumer perception, and market stability will impact the workforce and industry growth, and what workforce strategies must be implemented to keep pace with consumption demands.

Labor was another overarching concern identified by employers throughout the interviews and is considered a significant vulnerability for expanding the industry. It is important to consider how labor needs and labor efficiency will impact business growth, and what will be required to overcome limitations of labor in the industry. Additionally, environmental conditions influenced labor performance. Our findings were similar to the literature, where workforce constraints and labor shortages were stressors noted among West Coast shellfish growers (Ehrhart and Doerr, 2022; Green et al., 2023; Rice, 2025). Migrant labor and technological advancements were recognized as two labor strategies that could facilitate expansion of the sector. Participants that used one or both strategies discussed benefits of high productivity, strong resilience, and enhanced labor efficiency at their farm; drawbacks included exorbitant costs, burdensome administrative requirements, and the loss of utilizing local labor. Challenges often occurring in rural coastal regions, like limited and affordable housing and transportation and alternative work opportunities, could exacerbate the broader challenge, discussed in Kapetsky and Aguilar-Manjarrez, 2013, of spatial mismatch of labor supply and demands. Moreover, this study emphasizes that working conditions, job satisfaction, stressors, and technological advancements must be considered when assessing labor demands for industry growth, along with considerations of operation scale, species produced, location of production, and non-material benefits.

The future of the US shellfish aquaculture industry is dependent on many factors. Barriers and facilitators to shellfish cultivation have been identified globally (Fox et al., 2020; Green et al., 2023; Pei et al., 2025; Stewart-Sinclair et al., 2020). A plethora of stressors that could impact industry growth were identified by growers in this study, though stressor type, frequency, and intensity differed across farms. Our results are similar to Pei et al. (2025) where industry-led employment was the largest obstacle hindering China's green development plans of shellfish aquaculture (defined by economic sustainability, social acceptability, and economic profitability), though there are differing institutional and economic structures between China, the US, and other areas of the world, making direct comparisons challenging. Adaptive strategies, the response and effective adaptation to stressors (Green et al., 2023; Ward et al., 2022), found to potentially maximize industry growth in the US include policy and networking (e.g., permitting and regulatory modifications), farm management (e.g., ecosystem stewardship), and science (e.g., monitoring water quality; Green et al., 2023). Though adaptive strategies were not a frequent topic of discussion in the interviews, industry concerns noted by participants match with potential adaptive strategies addressed by shellfish growers in Green et al. (2023). It is common for shellfish growers to utilize alternative income sources due to highly susceptible risks associated with the aquaculture industry, such as inter-annual and intra-annual variability and environmental disruptions that could economically disadvantage the business (Cole and Chen, 2021). The results of this study depicted that all participating combination farms (i.e., diversified with oysters and hard clams; $n = 8$) expressed optimistic views of industry growth; potentially attributed to business diversification. Livelihood diversification has been noted as a central component of household economic stability, specifically in developing countries, and can improve resilience against socioeconomic stressors (Cinner and Bodin, 2010). For example, business diversification has been identified as an adaptive management strategy for Virginia fishers and West Coast shellfish growers (Green et al., 2023; White et al., 2025) and may be a potential strategy for maintaining economic and social satisfaction in Virginia and Florida's shellfish aquaculture sectors. If aquaculture is being considered as a long-term diversification tool, then governance strategies should be considered at the individual and

community scale to better understand potential opportunities and challenges (Stoll et al., 2019). Our study did not measure other potential income sources across employers and employees, and future research in this study area could provide greater insight to the financial dependence of the shellfish aquaculture industry. Addressing permitting and regulatory hurdles, supporting research for climate change and technological advancements, reinforcing the workforce, and increasing public awareness have been recommended (Ehrhart and Doerr, 2022).

The timing of this study could have influenced results, as Florida growers were interviewed during hurricane season, after the recent landfall of Hurricane Debby, and Virginia growers were interviewed during harsh winter months. An additional limitation to this study is the sampling approach. The combination of purposive and snowball sampling was an effective approach to reach employers, though employees proved more difficult to access. Additional effort is needed to further understand employee views. A larger portion of hard clam farmers were interviewed in Florida compared to Virginia based on sampling availability, which could have increased the rate of clam growers mentioning storm stressors. Peak season should be explored separately for market demands and for farm labor to further specify if there are differences in peak trends. Additionally, injuries were briefly discussed by some interviewees and could be considered in a future study for enhancing workplace safety and improving production efficiency (similar to Cavalli et al., 2020; Himawan and Munizu, 2025; Turner et al., 2018). The national average injury and illness rate for the private job sector is 2.4 cases per 100 full-time employees (FTE), compared to 4.1 cases per 100 FTE in the animal production and aquaculture sector (Bureau of Labor Statistics, U.S. Department of Labor, 2023a; Bureau of Labor Statistics, U.S. Department of Labor, 2023b); suggesting that the industry is higher risk. Interviewees were shellfish farmers, so the implications of job satisfaction were particularly significant for sector entry and not sector exit. Technologies were not compared across farms, so it is unclear which technologies improve or reduce productivity due to the magnitude of organizational structure and work variation across shellfish operations. Better capturing demographic representation of employers and employees through a larger sample size across the shellfish aquaculture sector could provide additional insight into the workforce. Despite these caveats, the findings offer valuable information for understanding the workforce in Virginia and Florida's bivalve shellfish aquaculture industries, and perhaps shellfish aquaculture industries around the US. Future studies should address these limitations and can expand research perspectives to different geographic locations (e.g., further along the East Coast, Gulf Coast, and West Coast), across various species of cultured bivalve shellfish, and by assessing all production methods used within the sector.

5. Conclusion

This study investigated perceptions of labor availability, working conditions, industry stressors and challenges, potential for sector growth, and the use of labor-reducing technologies among Eastern oyster (*Crassostrea virginica*) and hard clam (*Mercenaria mercenaria*) growers located in Virginia and Florida. The key findings of this research are nuanced by shellfish grower perceptions, which emphasized that labor constraints are a major obstacle for industry expansion. Labor needs can be greatly affected by a variety of factors within and outside of the business, such as location, scale, production method, and species produced. Non-material benefits (e.g., cultural identity) can motivate industry participation, but long-term employee retention is impaired due to a lack of material benefits (e.g., salary pay, health insurance, etc.) and challenging working conditions (e.g., at the job, environment). Non-material benefits may outweigh the use of labor-saving technologies; however, technology investment could improve worker retention by reducing overexertion. While growers favored the use of technology for reducing physical strain and improving production efficiency, technology was considered a complement to labor rather than a replacement.

There is potential that technology investment could allow for additional or new jobs in the sector, though, this is dependent on the impact of technology on overall production. Larger operations are more capable of adopting labor-reducing technologies and have greater financial capacity to offer competitive benefits, utilize migrant labor programs, and withstand employee turnover.

Stressors are not uniformly experienced across the shellfish aquaculture sector, which emphasizes the need for place-based research to best comprehend and address industry challenges. It is recommended that public perception, market demands, labor needs, policy reform, and environmental adaptation are collectively and individually addressed to support sustainable growth of the shellfish sector, alongside consideration of business diversification as a potential resilience strategy to industry stressors. Supporting factors that promote industry growth, while actively working to resolve constraints, could enable greater investment in labor and workforce refinement, providing potential for a more accessible industry and a larger, more competitive workforce. Further research is needed to better assess labor needs and potential labor tradeoffs across the Eastern oyster and hard clam industries. It is also recommended that labor is assessed in other economically important aquaculture sectors to generate employment opportunities, increase total aquaculture production, and satisfy food demands in the United States and globally. This study provides insight about the importance of labor in the bivalve shellfish aquaculture industry, and how the dynamicity of labor needs and technological advancements must be studied to grow the broader sector and to support a blue economy.

CRediT authorship contribution statement

Caela B. Gilsinan: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation. **Adriane K. Michaelis:** Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Andrew M. Scheld:** Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Funding acquisition, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.aquaculture.2026.744265>.

Data availability

The data that has been used is confidential.

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