Title: Identifying challenges of the US domestic seaweed aquaculture industry

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Abstract

Interest and engagement in aquaculture has been increasing in recent years to meet aquatic resource demands, and much attention has been directed to growing seaweed in the United States. However, research and regulatory environments have not kept pace with its growth, leading to challenges to expanding the industry, and in many cases, these developments may be ahead of available peer-reviewed literature, resulting in a dearth of information from industry participants about their needs and perspectives. The results of the first survey of industry members and those adjacent to the US domestic seaweed aquaculture industry are presented. Presenting contributions of participants throughout the supply chain from seaweed seed string producers through to processors and culinary professionals, and including regulators and researchers. A total of 268 respondents responded to the needs assessment survey, with engagement from fourteen states, primarily representing the U.S. northeast and west coasts. Results describe a wide differential in levels of industry engagement and

development across states with Maine providing an example of a well-developed industry, and others just beginning to develop seaweed growing permits and infrastructure. Respondents were asked to identify challenges which were then categorized as: (1) production systems (32%); (2) market opportunities, including both supply and demand (26%); (3) regulations (26%); and (4) post-harvest opportunities and infrastructure (i.e., processing facilities) (16%). Considering these challenges collectively, a holistic approach to scaling up the industry is needed to address challenges throughout the supply chain and across states. The paper concludes with recommendations for policy makers, regulators, extension professionals and researchers to assist this nascent industry in scaling up domestically by working to facilitate information transfer across states and roles within the industry to increase capacity at various levels of the supply chain, address remaining scientific questions, and move toward a regulatory framework for an inter-state (or domestic) industry.

Keywords: seaweed, kelp aquaculture, needs assessment, seaweed industry, United States

Highlights

- Seaweed aquaculture is garnering much attention in the United States as a sustainable food source and use of aquatic resources, yet research and regulations have not kept pace with its growth.
- The first needs assessment of US domestic seaweed aquaculture industry members and those adjacent to the industry is presented and discussed.
- Levels of engagement and industry development differ drastically across states and though some lessons can be transferred between states where the industry is further developed and those at earlier stages of development, differences between states may present different types of challenges.

- Scaling up the industry overall necessitates coordinated efforts at the federal level on certain issues, especially from a regulatory perspective.

- Industry-wide challenges were identified by participants throughout the value chain, suggesting that participants approach the industry from a holistic perspective.

- Policy makers, regulators, extension professionals and researchers to assist this nascent industry in scaling up, domestically, by facilitating information transfer within the industry to increase capacity and move toward a regulatory framework for a cross-state industry.

1. Introduction

1.1. United States seaweed industry

Interest and engagement in aquaculture has been increasing in recent years to meet aquatic resource demands, and much attention has been directed to growing seaweed in the United States (Alleway et al. 2023, Rubino 2023, Spillias et al. 2023, Kim et al. 2027, Grebe et al. 2019). Seaweed aquaculture in the US encompasses a variety of species and farming techniques, including ocean farms and tank-based systems. The predominant type of seaweed farming happening in the US currently is kelp farming, where kelp species are grown on ocean-based farms on the east and west coasts.

Although seaweed aquaculture has occurred in different locations in the United States since the 1970s, the current era of seaweed production began in 2010 in Maine, the state with the most developed industry (see Kim et al. 2019 for a brief history). At the same time, on the west coast

in California, seaweed was grown in land-based tanks for feedstock for abalone farms (CA Sea Grant 2024). In 2022, total production for farmed sugar kelp (*Saccharina latissima*) was reported to be approximately 3 million pounds, with other seaweed species reported to be under 2 million pounds combined (National Seaweed Hub 2023a). However, the United States only contributed 263 tonnes (or 0.0007%) to the global market (Cai et al. 2021).

Sugar kelp is the predominant seaweed species cultivated in 9 coastal states – Alaska, Washington, California, Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut and New York. In addition to ocean-based cultivation of sugar kelp, land-based tank cultivation of other species including dulse (*Palmaria* sp.), *Gracilaria*, *Ulva*,

is also occurring in Washington, Oregon, California and Hawaii (National Seaweed Hub 2023). Seaweed aquaculture is an emerging industry in the United States, with eleven states at varying scales of production ranging from small-scale cultivation for research purposes to significant commercial production (National Seaweed Hub 2023a). The industry is evolving at different rates across states, often outpacing capacities in research and regulatory environments to support its growth. As opposed to the kelp grown in Asia and imported to the United States, the kelp grown in the Americas and Europe is a sustainable specialty product in domestic markets due to its sustainable production systems along with domestic production, resulting in a higher level of supply chain transparency along with lower transportation costs (Cai et al. 2021, Grebe et al. 2019).

Potential economic benefits of this industry in the U.S. include job creation, increased revenue for existing aquaculture leaseholders, and diversification of products (Kim et al. 2017, Grebe et al. 2019). Since kelp aquaculture occurs mostly in winter and spring, it can provide a diverse source of employment and income for fishermen and shellfish growers during slower months

(Engle et al. 2018, Rubino 2023). Using seaweed for restorative aquaculture, (i.e., to improve water quality), is another potential benefit of this industry for coastal communities (Spillias et al. 2023, Alleway et al. 2023). Recent research is exploring new avenues for expanding seaweed farming. An inexpensive, mobile gear system for farming kelp was tested over three years in Maine. Designed to be integrated with existing fishing infrastructure, this system is proposed to facilitate fishermen to supplement their fishing income with seaweed farming (St-Gelais et al. 2022). There is also potential for expansion of seaweed aquaculture to the offshore environment, especially in conjunction with offshore wind farms, but the regulatory environment does not yet support this form of multi-use (Rubino 2023).

This purpose of this paper is to describe challenges and opportunities of the U.S. seaweed aquaculture industry as reported by its prospective and current participants. The seaweed aquaculture industry is similar to, but different from, both, other aquaculture products (i.e., shellfish) and land-based agriculture products (i.e., leafy greens), presenting unique challenges and opportunities surrounding its regulation and market chains. While seaweed aquaculture is thriving in specific states, this industry still differs greatly in its development between states, and bridging gaps between them to scale up is a major challenge to moving to a domestic industry.

1.2. Benefits of seaweed

Seaweeds are a healthy food source with high nutritional value. Although there are differences by species, seaweeds are generally low in fat and calories, high in dietary fiber, and they contain a range of essential nutrients including omega-3 and omega-6 polyunsaturated fatty acids, vitamins (i.e., A, C, E and B12), and iodine (FAO and WHO 2022, Cherry et al. 2019).

Polyphenols, found in seaweeds in various amounts depending on species and season, also provide important antioxidants to support human health (Zhang et al. 2022, Cherry et al. 2019, Roleda et al. 2019). Brown algae species, including sugar kelp, have high levels of protein, carbohydrates and antioxidants, along with low fat content (Nakhate and van der Meer 2021). Although the nutritional makeup of seaweeds has been established, more research is needed on humans' ability to absorb seaweeds' bioactive components (Cherry et al. 2019). Varying levels of nutrition were also found to change with season and type of processing, where for example, drying reduced nutrition levels more than blanching, for sugar kelp (Nielsen et al. 2021). For example, Nielsen et al. (2021) showed that although all seaweeds contain some Vitamin C, brown seaweeds, including *Saccarina spp.*, have relatively low levels and while they contribute to daily vitamin C intake, should not be considered a rich source of it for dietary purposes (Nielsen et al. 2021).

Health benefits of eating seaweeds have also been documented, and include regulation of blood sugar and cholesterol, weight loss, cardiac health improvement and improved intestinal health (for a review, see Forster and Radulovich 2015). In a review of the literature on the health benefits of eating seaweeds, Cherry et al. (2019) note that observational studies indicate potential benefits but, there is a need for more research to identify benefits and risks of consuming different types of seaweeds and at what levels. There are also concerns about health risks of seaweed consumption, especially in significant amounts and with regularity (Cherry et al. 2019). Potential risks associated with seaweed consumption include chemical, microbiological and physical hazards, with varying levels of risk associated with different species. An assessment of consumption of *Palmaria*, *Saccharina*, and *Alaria*, revealed low levels of risk of heavy metals (Roleda et al. 2019). Heavy metal concentrations are generally below toxic levels, however, there is consensus that heavy metal contamination in seaweeds depends

upon habitat or ecology, leading to inconsistent reported findings (Cherry et al. 2019, Kim et al. 2019). Microbiological hazards found to be associated with seaweed including *Salmonella*, *Vibrio*, and E. coli, and can be found in fresh or processed seaweed. Food safety protocols should be followed when handling and processing seaweed to limit introducing these hazards after harvesting (Barberi et al. 2020, Banach et al. 2020, Bilkra et al. 2018). Even with low bacterial levels, foodborne pathogens were found on samples of kelp using molecular testing methods (Barberi et al. 2020). Bilkra et al. (2018) found low levels of microorganisms on tested samples, however, and noted that dehydration and freezing both decrease the activity of water within seaweed, which limits microorganisms' ability to cause negative health effects in humans (Bilkra et al. 2018). Physical hazards that may be present in the ocean captured by algae include small pieces of shells and rocks (Zhang et al. 2022, Concepcion et al. 2020).

Production of seaweed-based products have a low carbon footprint, especially if grown and consumed in relative proximity as in the U.S. (Duarte et al. 2017, Cerca et al. 2023, Grebe et al. 2019). Seaweed is also a low-trophic food that requires few inputs. It can be farmed to supplement plants grown by agriculture without using arable land since it is grown in seawater and requires no freshwater or nutrients to grow after its nursery stage (Gephart et al. 2021, Forster and Radulovich 2015). Inputs are needed for juvenile seaweed plant cultivation including electricity, water, and nutrients such as phosphorus, magnesium, zinc and nitrogen, and outputs include liquid and solid waste (Nakhate and van der Meer 2021). Resources and energy are required to transport kelp between nursery production and farm site, and farm site to processing (Nakhate and van der Meer 2021). Cerca et al. (2023) note that growing seaweed also requires dedicated marine space where multiple uses have already been established (Cerca

et al. 2023). Further, ocean-farming practices for seaweed in the US do not use freshwater, fertilizers, or pesticides.

Seaweed aquaculture may also provide increased food security and corresponding decreased reliance on imported foods (Kim et al 2017, Forster and Radulovich 2015). In considering the potential for seaweed to contribute to food security, there is a need to answer questions about humans' ability to absorb seaweeds' nutrients and health benefits. As Cherry et al. (2019) and Forster and Radulovich (2015) note, seaweed consumption is assumed to be in relatively small quantities for these studies, not in amounts that can be considered significant contributions to dietary needs, as would be needed if seaweed were to be consumed to support food security.

1.3. Challenges and opportunities for the US seaweed aquaculture industry

Despite these potential benefits, environmental and social challenges to advancing the industry in the U.S. exist. The seaweed aquaculture industry needs social and economic improvements to scale up into a mature industry across states including: expanding processing capacity; establishing developed value chains; designing a regulatory environment to support growth; and local community acceptance of seaweed farms (Piconi et al. 2020, Rubino 2023). Additionally, challenges faced by aquaculture in general in the US, such as using public marine waters for private business, a complex governance system for leasing and regulation including a patchwork state-level regulations without coordinating policies at the national level, have compounding effects on the aquaculture seaweed industry (Lester et al. 2021, Knapp and Rubino 2016). New partnerships, for example, with other marine sectors, can be an opportunity for sharing marine space and facilities as well as knowledge transfer (Engle et al. 2018).

Cerca et al. (2023) identify barriers to scaling up of seaweed aquaculture in Ireland, similar to those facing the US industry, including difficult licensing procedures, questionable local support for cultivation sites, and lack of regulation for seaweed products. The responsible expansion of the industry depends on viable business models that enable socially responsible production systems and ecosystem considerations so that customers can connect the product with livelihoods in coastal ecosystems (Cerca et al. 2023).

A change in dietary habits to increase seaweed consumption is needed, along with public support to encourage that shift (Cai et al. 2021). An opportunity for the industry is the expansion in the use of seaweed in food in the Western world due in part to its sustainable cultivation practices and in part, to its nutritional profile - high content of minerals, vitamins and trace elements, high dietary fiber and protein (Blikra et al. 2019, Cherry et al. 2019, Engle et al. 2018, Grebe, et al. 2019). Figueroa et al. (2023) note that mindful consumers looking for nutritional and sustainable foods are likely to incorporate seaweeds into their diet if tasty and appealing products are developed. Recent research into food applications has included high-value products with health benefits that can be added to foods, for example pasta, to improve nutritional quality (Zhang et al. 2022).

Grebe et al. (2019) describe the kelp grown in the Americas and Europe as a specialty product, distinct from its Asian counterpart which is treated and consumed as a commodity. One approach to this product distinction is the development of fresh and fresh-frozen kelp products like kelp noodles and slaws (Kim et al. 2019). Another is to promote aquaculture seaweed as providing a “sense of place” as a socio-cultural service provided by coastal ecosystems (Cerca et al. 2023). They suggest that growers create social value in growing a sustainable product while

being connected to local settings in coastal communities but note the challenge is to capture and deliver this value to customers for a profit (Cerca et al. 2023).

1.4. The need for industry participant perspectives

The future of seaweed's role has been considered in the European food system and global value chains (Cerca et al. 2023, Banach et al. 2020, Campbell et al. 2019), and using an ecosystem approach to kelp aquaculture considering the environmental and social impacts in the Americas and Europe (Grebe et al. 2019). A recent assessment of marine aquaculture, including seaweed, has also been considered from a policy perspective for the United States (Rubino 2023). However, the US domestic industry is rapidly developing and, in many cases, these developments may be ahead of available peer-review literature, resulting in a dearth of information from industry participants about their needs and perspectives.

Established in 2019 by the National Oceanic Atmospheric Administration's National Sea Grant Program, the National Seaweed Hub is a collaboration of eleven Sea Grant programs - Alaska, California, Connecticut, Maine, New Hampshire, New York, Oregon, Rhode Island, Washington, Wood Hole, and the National Sea Grant Law Center - that identified the need to understand the seaweed aquaculture industry and its associated sectors through the perspectives of its members to guide the National Seaweed Hub's extension and outreach efforts. In response to this need, a needs assessment was conducted. Responses to the needs assessment survey of the U.S. seaweed aquaculture industry as reported by its prospective and current participants are presented in this paper. Respondents include individuals throughout the value chain of cultivated seaweed from permitting and seed production through point of sale to consumers. The seaweed aquaculture industry is similar to, but different from, both, other aquaculture

products (i.e., shellfish) and land-based agriculture products (i.e., leafy greens), presenting unique challenges and opportunities surrounding its regulation and market chains. In addition, this nascent industry has footholds in specific states, especially Maine, but faces challenges in scaling up to a larger geography.

First, there is a summary of contextual information from survey respondents grouped by their role in the domestic seaweed industry, followed by needs identified by each group. Finally, the paper describes categorized challenges of the industry defined by stakeholders across the industry. This information will be used by the National Seaweed Hub to assist the industry and increase access for consumers to domestically-grown seaweed. These results are presented to guide potential and current industry participants, decision-makers, policymakers, and researchers in engaging with the U.S. seaweed aquaculture industry to determine future directions.

2. Methods

2.1. Survey development with Seaweed Hub members

The needs assessment was collaboratively developed with National Seaweed Hub extension staff representing each of the participating Sea Grant programs. This survey effort was approved by the Institutional Review Board for Human Subject Research at the University of Rhode Island (IRB#1546677-1).

Respondents selected one or more roles from those identified within the seaweed aquaculture industry (For further definition, see Supplemental Material).

Based on their role selection(s), respondents were presented with questions specifically based upon their sector role(s). However, to identify issues across geographies and roles, some of the survey questions were asked of all participants regardless of their role (e.g., identifying challenges for the industry as a whole). National Seaweed Hub extension staff are well connected with participants in this industry in their states, therefore, this effort brought together the national network to collect input from a broad geographic range of stakeholders. These responses represented an industry at differing stages of development, and results should be viewed as an overall snapshot of industry needs while recognizing state and regional differences in scales of production and regulations. The authors cannot estimate the representativeness of this sample due to the nature of the industry, for which we have no official numbers.

2.2. Survey topics

Questions were designed to identify the status of the industry (i.e., production volumes, product forms, and market outlets); describe the contributions of different roles to the industry; and identify challenges and opportunities for future directions of the industry. For all respondents, survey questions included state(s) in which respondents engaged with the industry; role(s) in the industry; years of experience; species of seaweed grown or used; and challenges. Additional questions differed by identified sector role (i.e., grower, processor, etc.), and included specific questions pertaining to their selected role (e.g., price information for growers and processors; and familiarity with preparation for culinary professionals).

2.3. Survey administration

The survey was developed and administered on the Qualtrics XM platform. National Seaweed Hub members sent recruitment emails, including an anonymous link to the survey, to their

respective list of contacts connected to the seaweed aquaculture industry to solicit responses. Approximately two weeks later, extension representatives followed with a reminder email. The initial wave of responses was collected between January 6, 2019 and February 18, 2020. A second wave of responses - February 22 through April 1, 2020 - were collected following a preliminary presentation of results, to provide stakeholders in California and Hawai'i (not originally represented in the National Seaweed Hub), an opportunity to contribute their perspectives. Responses were analyzed using SPSS 29.

3. Results

3.1. Response overview

In total, there were 268 responses to the needs assessment survey, with engagement from fourteen states, primarily representing the U.S. northeast and west coasts (Figure 1.). Respondents were asked to report all states in which they engaged in the industry. The three most-commonly reported states were Washington, Maine and New York. Higher numbers of responses should not be interpreted strictly as more interest due to relative population size and development of the industry. However, Maine's seaweed industry is both the largest and most well-developed and therefore, Maine's high response reflects these aspects. There is a high level of interest, engagement with extension, and potential opportunity surrounding growing seaweed in Washington state, however, there are currently only three farms growing seaweed (National Seaweed Hub 2023a). A high number of respondents also reported engagement in the industry in Alaska where there is significant interest and opportunity with a large coastal and ocean area, and only second to Maine in seaweed landings in 2022 (National Seaweed Hub 2023a).

Respondents represented a diversity of roles in or adjacent to the industry from nursery/seed producers through culinary professionals; with prospective growers (N=88), researchers (N=91) and permitted growers (N=56) represented in highest numbers (Figure 2). The number of responses is greater than the number of respondents because selection of roles and states of engagement were not mutually exclusive. Therefore, given the diversity of perspectives represented by these responses, the following section provides an overview of survey responses by selected roles in the seaweed aquaculture industry.

3.2. Responses by industry role

3.2.1. Permitted growers

Forty-five permitted seaweed growers responded to the needs assessment, with the largest proportion of individuals reporting 1 to 3 years of experience (N=15, 38%), 13 respondents reporting greater than 5 years of experience, 8 reporting less than 1 year, and 4 respondents reporting 4 to 5 years of experience.

Reported experience with the process of obtaining a permit for growing seaweed differed widely among permitted growers, with costs ranging from $0 to $5,000, and timelines ranging from less than 6 months to more than 2 years. However, the majority of permitted growers reported a permitting process timeline between 6 months and 2 years (68%).

Permitted growers report growing a variety of seaweed species. The majority of respondents reported growing sugar kelp (55%), while *Gracilaria* and sea lettuce (10% each), and bull kelp and *Alaria* (8% each), were also reportedly grown by respondents. Of the growers reporting sales of their seaweed, most sold their product fresh (Figure 3). However, more than a quarter

of growers reported they hadn't yet sold seaweed. Sugar kelp was the most-commonly reported species of seaweed grown by permitted growers, and they most often sold this seaweed fresh. Fresh sugar kelp has a short shelf-like, is heavy and complicated to ship while maintaining product quality and food safety.

Seventy-one percent of growers reported harvesting seaweed in the year prior to survey administration, and 84% percent of permitted growers reported growing seaweed from seed provided by a nursery. Ten growers reported to not have harvested any seaweed in the year prior to the survey and one grower preferred not to disclose the amount they produced. Of the twenty-six growers that reported harvesting seaweed, half of them reported producing less than 1,000 pounds and 39% reported harvesting more than 5,000 pounds while only 8% reported harvesting between 1,000 and 3,000 pounds and 4% reported harvesting between 3,000 and 5,000 pounds. There are many new seaweed growers entering this industry, as evidenced by the more than one quarter who have permits but have not yet sold any seaweed. Regarding buyers for this product, forty-nine percent of permitted growers reported they had identified a buyer for their seaweed in the year prior to the survey. Eleven percent reported this question didn't apply to them, suggesting that these growers supplied their product for research or some other outlet for which they didn't require a buyer.

Forty-nine percent of growers who reported selling their seaweed, also reported processing it in some way before selling it (N=17). Of these growers, most reported drying it themselves (36%). However, growers also reported processing their seaweed into powdered, blanched, frozen, noodles (blanched and frozen), and pureed forms before selling it. Growers reported selling their seaweed to a variety of outlets (N=37), with restaurants and chefs the most common buyers (22% each), and in lesser numbers, institutional buyers (19%), processors (11%)

and other outlets including wholesalers, online direct sales, farmers and unspecified other buyers (collectively, 24%) made up the remaining reported sales outlets. Although 48% of growers preferred not to disclose the prices they received for their product, reported prices growers received for their seaweed of all species, and in both fresh and processed form ranged from $0.55 to $20.00/lb (N=14, median = $5.00). The higher end of this range of prices can be attributed to niche marketing, usually of fresh seaweed in line with recommendations of Grebe et al. (2019) and findings by Cerca et al. (2023) in the Irish seaweed aquaculture industry.

Due to lack of processing infrastructure to increase shelf-life, the majority of permitted growers sell most of their seaweed in its fresh form, mainly to restaurants and chefs. The range of prices suggests a wide variety of outlets for the harvested product, and prices are likely to differ greatly between geographies with differing levels of industry engagement. Almost half reported identifying a buyer for their product. Almost a third of growers reported not needing to find a buyer, which suggests there is a significant outlet for seaweed for research purposes, an alternative to the commercial market. However, research should not be considered a viable outlet for seaweed for a mature, financially stable industry because research is highly subsidized (Duarte et. al. 2017; Theurkauf et. al. 2021).

Over three-quarters (79%) of permitted growers reported they deployed seeded-string in the year the survey was administered. The majority of growers reported buying seeded-string from a commercial nursery (32%), with other growers obtaining seeded-string from non-profit sources (27%), culturing their own (24%) and a small portion from university suppliers (9%). Of the growers who reported they did not deploy seeded-string, the reasons varied including high cost of seeded-string, farm site not ready, and poor growth.

Most-common industry challenges reported by permitted growers were market options (20%), access to seeded-string (15%), and profitability ((14%), respectively (Figure 4a). The most commonly-reported challenges for growers in the industry – market options, access to seed, and profitability – are indicative of a nascent industry where several aspects of the market chain need to be developed before the industry can thrive (Buschmann et. al. 2017).

3.2.2. Processor

Thirty respondents reported that they are seaweed processors in the domestic seaweed industry. This industry includes processors of both farmed and wild harvested seaweed. Almost half of seaweed processors reported 1 to 5 years of experience in processing seaweed (47%). Eight respondents reported more than 5 years of seaweed processing experience, four respondents reported between 4 and 5 years of experience, and three respondents reported to have less than 1 year of experience processing seaweed. Five respondents reported they had not yet processed seaweed. Processors reported processing more than 50 species of seaweed in the year prior to the survey. The inclusion of processors of wild harvested seaweed accounts for this high species diversity because the U.S. seaweed industry currently farms very few species. Sugar kelp (N = 15) was the most-commonly reported species for processing, followed by dulse (N = 7), and bull kelp and sea lettuce (both, N = 6). Processors in the year prior to the survey overwhelmingly purchased their seaweed from domestic sources (N = 23) as opposed to imported sources (N = 1) and more often bought their seaweed from a local grower (N = 13) rather than a wild harvester (N = 10). Three respondents reported processing self-grown (N = 2) or self-harvested (N = 1) seaweed in the year prior to the survey. When asked about purchasing, seven processors reported that they purchased their seaweed at a set price, nine reported that they did not purchase at a set price, and six respondents (20%) preferred not to disclose the price for which they purchased their seaweed to be processed. Of those processors

who purchased raw seaweed of any species (including farmed and wild-harvested) and reported prices, the prices ranged from $0.56/lb to $22/lb (N = 5, median = $3.00). Processor respondents most often reported consistent supply (28%) and source options (26%) as challenges (Figure 4b).

Many processors responding to the survey reported to have had several years of experience processing seaweed, suggesting that this role is relatively more experienced than others in the industry, like permitted growers and nursery producer. This is likely because processors have experience in longer-established wild harvest seaweed industries. Processors reported to work with a wide variety of seaweed species with contributions from both aquaculture and wild harvest sources. There was a large range in the prices processors reportedly paid to purchase raw seaweed which could reflect the large number of species handled in processing and variations in seaweed quality.

3.2.3. Nursery

A total of 26 respondents reported producing seaweed seed (i.e. seeded-string for kelp growers). Half of these respondents (N = 13) did not sell their product. Of the producers who reported that they sold their seed (N = 13), 85% (N = 11) of them reported to have the capacity to produce more than 30 spools of seed while 8% reported a capacity of 1-10 spools and 8% preferred not to report the number of spools. Respondents focused their efforts on sugar kelp (N = 10) and bull kelp (N = 4), with one respondent reportedly producing *Alaria spp*. as well. The frequency of industry challenges identified by nursery respondents were distributed across topics (Figure 4c). Finding buyers was the most-commonly reported challenge (21%), however, each of the other industry challenge options provided in the survey was selected by several nursery respondents.

Only half of nursery respondents reported that they sold their product. This could be due to new entrants into the industry, as many new seaweed nurseries have been established in the past five years and may not yet have the capacity to sell their seed. However, data on years of experience was not collected from this group. Other nursery producers may be growing seed for research or personal use purposes, and not for sale. Seeded-string producers focus mostly on kelp species (primarily sugar kelp and bull kelp). Most nursery producers have the capacity to produce over 30 spools of seed and nursery respondents most-often reported finding a buyer for their seed. These results suggest that nursery production could be scaled up as the industry grows.

3.2.4. Culinary professional

Nine culinary professionals responded to the needs assessment survey, eight of whom had reportedly prepared seaweed in the year prior to the survey and one for whom it had been 1 to 3 years since they prepared seaweed (Table 1. Culinary Professional Summary of Responses). Respondents used a variety of forms of seaweed, most often reporting dried 25%, fresh and frozen (21%, each), but also blanched, powdered, pureed and salted (N=1, each). Culinary professionals reported experience preparing a wide variety of species in the past year, with kelp, nori and wakame (27%, 18% and 15%, respectively) reported most often. When asked about species they are most interested in preparing, kelp (28%) was the most often reported, followed by dulse and nori (15% and 13%, respectively). Most-commonly reported uses for seaweed in food prepared by culinary professionals included soup (with seaweed as an additive) (29%), followed by seaweed salad, and as an additive or spice (25%, each). Other uses reported included seaweed as noodles in a mixed dish, seaweed snacks/chips, and as a

478 substitute for spinach (N=1, each). Culinary professional respondents purchased seaweed from
479 domestic sources (N = 6) slightly more often than from imported sources (N = 5). Of the culinary
480 professional purchasing from imported sources, four (67%) reported they purchased seaweed
481 from a local harvester. There were only 2 responses to prices paid for locally-produced
482 seaweed, $5/lb and $30/lb.
483
484 Table 1. Culinary Professional Summary of Responses

		N	Percentage
Last time prepared seaweed	<1 year ago	8	89%
	1-3 years ago	1	11%
Total		9	
Forms of seaweed used	Fresh	5	21%
	Dried	6	25%
	Powdered	2	8%
	Blanched	4	17%
	Frozen	5	21%
	Pureed	1	4%
	Other	1	4%
Total		24	
Types of seaweed used	Kelp	9	27%
	Nori	6	18%
	Wakame	5	15%
	Dulse	4	12%
	Kombu	3	9%
	Alaria	2	6%
	Laver	1	3%
	Irish moss	1	3%
	Other	2	6%
Total		33	
Types of seaweed of interest	Kelp	13	28%
	Dulse	7	15%
	Nori	6	13%
	Kombu	5	11%
	Wakame	4	9%
	Alaria	4	9%
	Laver	3	6%

	Irish moss	3	6%
	Other	2	4%
Total		47	
Culinary uses of seaweed	Soup	7	29%
	Seaweed salad	6	25%
	Seaweed as spice	6	25%
	Seaweed snacks/chips	4	17%
	Seaweed noodles	4	17%
	Other	4	17%
Total		24	

Challenges most often identified by this group included availability of the desired form of seaweed (20%), obtaining locally-produced seaweed and consumer demand (16%, each) (Figure 4d). Culinary professionals also reported challenges in sourcing seaweed and seaweed products in the desired form, but with more growth, market connections could be made more easily. Consumer demand was also reported as a challenge for culinary professionals indicating consumers are not currently driving demand for value-added seaweed products and seaweed in restaurant dishes.

Culinary professionals who responded to the survey expressed high levels of interest in sugar kelp, and other types of seaweed. These results support the expansion of the seaweed aquaculture industry for culinary purposes. Culinary use of fresh (unprocessed) seaweed can only be supported for a short time since the shelf-life of sugar kelp is short. However, reported use of different forms of seaweed could provide an opportunity for processors as they expand their capacity to supply culinary outlets with different forms of their product.

3.2.5. Regulators

There were 43 responses from regulators to the survey (Table 2. Summary of regulator responses). The majority of regulators reported to work at the state level (69%), with others representing federal, municipal, tribal and 'Other' jurisdictions.[1] Respondents reported their regulatory focus was most often aquaculture permitting (72%), followed by public health/food safety (28%). Regulators reported seaweed growers (44%), followed by seaweed wild harvesters (18%), processors (15%) and dealers (13%) as their primary audiences, with the remaining respondents reporting a variety of different audiences in smaller percentages.

Table 2. Summary of Regulator Responses

		N	Percentage
Jurisdiction	State	29	69%
	Federal	8	19%
	Municipal	3	7%
	Tribal	1	2%
	Other	1	2%
Total		42	
Regulatory Focus	Aquaculture permitting	33	72%
	Public health/food safety	13	28%
Total		46	
Primary audience	Growers	36	44%
	Wild harvesters	15	18%
	Processors	12	15%
	Dealers	11	13%
	Culinary professionals	1	1%
	Other	7	9%
Total		82	
Additional management entities reviewing applications	1 - 3	11	34%
	4 - 6	12	38%
	More than 6	9	28%
Total		32	

[1] The 'Other' response did not include any further information.

Aquaculture permitting regulators reported a complex regulatory structure for prospective seaweed growers which differs between states. Permitting regulators most often reported "4-6" management entities (other than the one they represented) reviewing aquaculture permit applications (38%). However, this number differs between states with 34% of regulators reporting 1 – 3 other reviewing entities and 28% of regulators reporting more than 6 other management entities reviewing applications. Costs, and the cost structure to maintain an aquaculture permit to grow seaweed also differs between states. Regulators reported vastly differing cost structures for growing seaweed. Fees are charged for permit applications; annual per acre charges; and additional charges such as yearly license renewal fees and rental fees to use the submerged lands on which the seaweed is grown. Permitting regulators also reported that seaweed growers are required to report seaweed landings in states for 21 of 29 respondents.

Differing regulatory requirements and cost structures between states can make working in this regulatory environment difficult for regulators and for others in the industry. Additionally, these costs and cost structures are evolving in many states, as the industry is becoming more established, creating further complexity for permitting regulators who are responsible for providing updated information to their constituents.

Permitting regulators' most-commonly reported gear design and/or farming infrastructure as a challenge to the seaweed industry (19%) while other industry challenges commonly reported included clear regulations (16%); information on the spread of non-native species, pathogens and harmful algal blooms (HABs) (13%); source of seed (12%); and assistance for growers to

navigate the permitting process (12%) (Figure 5a). Interestingly, several permitting regulators (5%) also added comments identifying a lack of market as an industry challenge.

Commonly reported challenges by permitting regulators suggest an emerging industry in which gear design and farming infrastructure, clear regulations and assistance for growers to navigate the permitting process are still evolving. Concerns (i.e. information) about seaweed farms spreading non-native species, pathogens and HABs; and understanding environmental conditions for favorable growing environments were also reported challenges for regulators working on permitting seaweed aquaculture. Though these regulators are not responsible for seaweed after it has been grown, their reported concern for a lack of market illustrates their awareness of the larger need for increased options for growers to sell their seaweed.

Regulators focusing on public health and food safety most-commonly reported industry challenges related to food safety (26%), but also respondents also reported other challenges including clear regulations (23%), education on regulations for industry participants (21%), and information about safe growing environments (18%) (Figure 5b).

Public health and food safety regulators reported challenges suggesting that the science (or information to support regulations) and the regulations themselves, are not yet adequate for regulators to effectively guide participants in the industry.

3.2.6. Prospective growers

Prospective growers (N = 76) reported anticipated engagement most often in Washington state (N = 34), New York (N = 14) and Alaska (N = 13) (See Figure 2). Respondents most-commonly reported environmental benefits (48%) and source of income (46%), as their interest in growing

seaweed (Table 3. Summary of prospective grower responses). Respondents' interest is most often in growing sugar kelp (27%), however, there was interest in a wide variety of species reported. Prospective growers reported to be currently working in a variety of related industries, most-commonly aquaculture (48%), commercial fisheries (13%), and science and research (8%).

Table 3. Summary of prospective grower responses

		N	Percentage
Interest in industry participation	Environmental benefits	62	48%
	Source of income	59	46%
	Other	7	5%
Total		128	
Types of interest	Sugar kelp	54	27%
	Bull kelp	26	13%
	Allaria spp.	25	13%
	Gracilaria	15	8%
	Dulse	29	15%
	Nori/Laver	22	11%
	Irish moss	11	6%
	Sea lettuce	16	8%
Total		198	
Current industry of work	Aquaculture	29	48%
	Commercial fisheries	13	22%
	Science & Research	8	13%
	Marina/maritime infrastructure-related	4	7%
	Biofuels	3	5%
	Food	3	5%
Total		60	

At the time of the survey, these respondents were not actually growing seaweed yet, and were at different stages in the process of becoming a permitted grower. Their reported industry challenges (N=182) suggest a need for assistance with technical aspects of production, such as

574 setting up a farm (22%), more information on the permitting process (19%), market
575 opportunities (16%), and access to seaweed seed (15%) (Figure 5c).
576
577 The high level of response from prospective growers illustrates a high interest in growing
578 seaweed products, however, because they are not yet actively participating in the industry,
579 these respondents may not be as informed as those in other roles.
580
581
582 3.2.7. Researchers

583 Sixty-three researchers responded to this survey, representing interests from a wide variety of
584 biophysical and social science research related to seaweed. The most-commonly reported
585 research foci are ecology (21%), biology (19%) and food science and product development (14)
586 (Table 4. Summary of researcher responses). More than two-thirds (81%) of researcher
587 respondents reported to be actively engaged in seaweed-related research at the time of the
588 survey, representing a spectrum of research including seed cultivation, food pathogens,
589 ecological design of farms, and seaweed's potential to sequester carbon. Types of seaweed of
590 interest for researchers reported most often are sugar kelp (27%) and bull kelp (15%). However,
591 researchers reported to have worked with many other seaweed species. Most often,
592 researchers reported working with seaweed producers and regulators (28%, each) on their
593 research, while also reporting research with processors (16%), value-added processors (14%)
594 and culinary professionals (14%) in significant proportions.

595 Table 4. Summary of researcher responses

		N	Percentage
Research Focus	Ecology	45	21%
	Biology	40	19%

	Food science & product development	31	14%
	Production technology	27	13%
	Non-food uses for seaweed	26	12%
	Economics	21	10%
	Social science	17	8%
	Other	8	4%
Total		215	
Currently involved in related research	Yes	47	81%
	No	11	19%
Total		58	
Types of seaweed of interest	Sugar kelp	45	27%
	Bull kelp	25	15%
	Alaria	14	8%
	Dulse	13	8%
	Nori/Laver	10	6%
	Irish moss	7	4%
	Gracilaria	19	11%
	Sea lettuce	19	11%
	Other	14	8%
Total		166	
Partner role within industry	Seaweed producers	37	28%
	Regulators	37	28%
	Processors	21	16%
	Culinary professionals	19	14%
	Value-added processors	18	14%
Total		132	

596

597 Industry challenges most-commonly reported by researchers were guidance on the permitting
598 process (22%), understanding post-harvest opportunities (both infrastructure and market
599 outlets) (21%), followed by concerns about food safety (13%) and access to local seeded-string
600 (12%) (Figure 5d).

601

602 There was a high level of interest in research on seaweed and the domestic seaweed industry in
603 the research community with a variety of topics represented. Researchers reportedly are well-
604 integrated into the industry, working with all other seaweed sectors represented in the survey.
605
606 ### 3.3. Overall U.S. Seaweed Industry Challenges
607
608 Responses about seaweed industry-wide challenges were separated into the following four
609 categories: (1) production systems (32%); (2) market opportunities (26%); (3) regulations (26%);
610 and (4) post-harvest opportunities and infrastructure (i.e. processing facilities) (16%). These
611 categories were identified to include industry members in various roles together to work
612 together toward solutions that would be beneficial for the overall industry. Production systems
613 includes concerns related to obtaining seaweed seeded string, managing nursery operations
614 and maintaining quality in seaweed seed production. Market opportunities includes both
615 supply and demand concerns for connecting seaweed – in various product forms – to several
616 audiences including processors, buyers for culinary uses, and consumers. Regulations topics
617 cover concerns about the regulatory environment throughout the value chain from obtaining
618 seaweed seed, through permitting for growing and transporting seaweed, to processing and
619 producing safe seaweed products for end users. Finally, post-harvest opportunities and
620 infrastructure involve concerns about transporting, storage and processing seaweed while
621 maintaining it taste, nutrition and safety.

622 Industry challenges in each of the categories were identified by respondents engaging in the
623 seaweed industry in most states, except those (i.e., Oregon and Hawai'i) with less than 10
624 responses (Figure 6). The distribution of challenges is fairly even across categories, indicating
625 that these challenges resonate in each state. Two exceptions to this pattern are responses from

Alaska and Washington respondents. Alaska respondents more often reported challenges related to production systems (35%) than the other categories, suggesting that the industry in Alaska is primarily focused on growing seaweed (i.e., producing seaweed), and less so on the latter parts of establishing an industry (i.e., markets, processing, regulations). Washington is another exception with more respondents identifying production systems and regulations (both, 35%) than market opportunities (23%), and post-harvest identified the least often (8%). These results indicate that participants in Washington are also focusing on earlier stages of establishing the industry, both growing seaweed and establishing the industry's regulatory structure.

Although three of these categories - production systems, post-harvest opportunities, and market opportunities – focus on discrete stages of the seaweed industry, challenges in these areas were highlighted by respondents from many different roles (Figure 7). Additionally, regulations, which affect each of the other stages of the industry, is also recognized as a challenge by almost all roles (the exception is culinary professionals). These results suggest that respondents - regardless of their specific role – view the industry from a holistic perspective.

4. Discussion

4.1. Geography and Roles Represented

Respondents to this survey primarily represented US states in the northeast and west coast. These geographies are where the seaweed aquaculture industry is most developed and/or where there is the most interest. Responses include contributions from members involved in, or associated with, the industry from seaweed seed production through market opportunities.

Thus, the results can be viewed as representing a holistic view of the US domestic seaweed aquaculture industry.

4.2. Seaweed Industry Challenges

Respondents from all geographies and roles identified industry challenges falling into each of the four categories. This suggests that actors within the industry are aware of not just their challenges related to growing, processing and using seaweed, but that they are aware of the need to address the entire market chain to support growing the industry as a whole. Challenges related to production systems are reported in highest proportions in Alaska, Maine, Massachusetts and Connecticut. These states all have established seaweed growers who are actively facing the challenges of acquiring seeded string, setting up farms and transporting their seaweed product to be processed. Responses from California and Oregon are also higher for production systems challenges, which is likely surrounding establishing production since these states are at the very beginning of establishing a seaweed industry with two active permits for California and no ocean-based permitted farms in Oregon yet. Challenges related to market opportunities are reported in higher percentages in Washington state. This is likely associated with two significant operations just beginning to produce seaweed in significant amounts in Washington, for which growers will need markets to sell their seaweed. Post-harvest infrastructure challenges are reported in relatively lower proportions by respondents in all states responding to the survey except for Rhode Island, where there is a lack of seaweed processing capacity within its borders. For states where seaweed growers are well-established, most growers have already established their post-harvest buyers or processing but for states with new growers, respondents are more likely to be concerned with production systems and market opportunities in early years of establishing the industry. Regulatory challenges are

reported in higher proportions in New York and Washington states. In New York, this may be related to a lack of clarity in post-harvest regulations for seaweed, given the interest in market opportunities in this state, and it may also be related to ongoing efforts to survey areas to determine locations where seaweed farms will be permitted. In Washington, the two new growers are likely facing regulatory questions as they begin to navigate the process of growing and transporting seaweed.

Concerns about supply and demand are reported challenges for more than a quarter of respondents. Recognizing and marketing US-grown seaweed as a niche product, as recommended by Grebe et al. (2019) can provide marketing opportunities. These marketing opportunities can tap into the demand from consumers interested in nutritional and sustainable foods, with further development of culinary dishes and products showcasing this product (Figueroa et. al 2023). These findings also lend themselves to exploring the need for development of new seaweed-based foods as a dual opportunity for the culinary industry to work with researchers to develop new dishes and to work with nutritionists to learn more about the ability for humans to absorb nutrients from seaweed (Chambers et al 2015, Cherry et al. 2019).

Cerca et al. (2023) note that demand for seaweed as a raw material is reported to be high, but challenges of processing capacity and methods, and lack of consumer awareness about preparing it can be a barrier. To address this concern, production systems, post-harvest processing, food safety, market development, and regulatory guidelines are all needed to enable the industry to take advantage of an opportunity to meet higher consumer demands for seaweed.

At the time the survey was conducted, some states represented were home to an established, seaweed industry (i.e., Maine) while others were just beginning to permit seaweed growers (i.e., New York and Washington). However, some seaweed-growing states are just beginning to establish the necessary infrastructure and regulations to support the industry while others, such as Maine, have established nurseries, growers, processors, and markets. Therefore, survey responses represent perspectives from participants acting (or interested in acting, in the case of prospective growers) at different regional stages of development. These findings suggest that those states at earlier stages of industry development can learn from the experience of those with a more-developed industry. However, differences in geographic, demographic, regulatory and economic environments can present new kinds of challenges as these states develop their seaweed industry.

A major challenge to establishing a domestic seaweed industry for all participants is how to expand beyond in-state operations and supply chains to regional and national market chains, while accommodating the differences in scales of production, availability of infrastructure, and regulatory environments.

4.3. Working to address industry challenges

Survey results were used to identify common themes across geographies and roles in the industry. Challenges suggest an industry at a vital point in development, where technical, regulatory, and infrastructure needs must be addressed to expand seaweed aquaculture into a mature industry in the US.

Based on the results presented above, the Seaweed Hub established four virtual work groups, facilitated by the Seaweed Hub members, to support expansion of this emerging industry. Work group participants represented a mix of roles in the industry to ensure that the strategies they developed reflected diverse perspectives and met industry-wide needs. Since the survey was conducted, these groups have made progress in each category:

(1) The Production Systems Work Group focused on nursery supply and connecting potential providers to potential buyers. The group developed a National Seaweed Nursery Directory of seaweed nursery suppliers and the products they provide. This directory is publicly accessible on the National Seaweed Hub's website and updated regularly as new suppliers emerge (National Seaweed Hub 2023b).

(2) The Post-harvest and Processing Infrastructure Work Group developed a guide providing key parameters for testing in seaweed, and the importance of setting standards for each for the industry. The information will inform processors, regulators and end-users about food safety and product quality considerations.

(3) The Market Opportunities Work Group produced a publicly accessible National Seaweed Marketing Toolkit that includes targeted marketing language, social media assets and marketing tips for growers to utilize in their marketing and public relations strategies (Seaweed Hub 2023c).

(4) The Regulations Work Group created a reference document comparing two similar federal food safety programs (Seafood HACCP and FSMA Preventive Controls) enforced by regulatory agencies (Seaweed Hub 2023d). This resource provides guidance to

748 seaweed businesses to determine which program applies to their operation and
749 considerations for transitioning between types of businesses.
750
751 ### 4.4. Limitations of the study
752 The COVID-19 pandemic at its associated closures, which affected development of the industry
753 and its markets, began just after this needs assessment began. Continued contact with
754 members of the industry, especially through the Seaweed Hub initiative, confirm that results
755 presented here are consistent with current needs despite unanticipated COVID-19-related
756 interruptions.
757
758 Certain aspects of the domestic seaweed aquaculture industry differ drastically between states
759 and are continuously changing in response to needs. Therefore, data on permitting processes
760 and associated costs are presented to provide an understanding of the range of industry
761 members' experience, but should not be used as a guide for prospective entrants.
762
763 ## 5. Conclusions
764 The U.S. domestic seaweed aquaculture industry is at a pivotal point in its development, in
765 parallel with global challenges to seaweed industry expansion such as uncertain demand,
766 questions of nearshore farm site availability, and reliable seaweed value chains (Cai et al. 2021).
767 Actors both within the industry and adjacent to it, are eager to address the needs and
768 overcome the challenges. The future growth of the industry depends upon both internal and
769 external forces of interest, markets, and institutional capacity to facilitate growth of this
770 industry from small, state-level focused operations, to a well-developed domestic industry. This
771 paper summarizes results of a needs assessment of prospective and current participants in the

U.S. seaweed aquaculture industry. Challenges in production systems, market opportunities, regulations and post-harvest opportunities were identified by participants in various roles within the industry, and across states involved in the industry at various stages of development.

The following are several initiatives, ongoing and recommended, that can assist in overcoming the challenges and taking advantage of the opportunities identified by survey respondents. The National Seaweed Hub continues to address emerging needs of the domestic seaweed industry through (1) sharing evidence-based information about the industry with resources developed in collaboration with seaweed industry members and (2) providing opportunities for seaweed industry members to connect with each other through a variety of mechanisms, enabling them to continue to collaborate. These opportunities for sharing information can help states in earlier stages of industry development, e.g. Washington and New York, learn from the experience of those states in latter stages of development, e.g. Maine and Alaska, while allowing the newer states to the industry to bring their unique ideas which states with more experience may be able to use as well.

Partnerships between science and industry can be used to fund continued work to address the challenges identified here. The science/industry partnerships have been a successful way to address information gaps in other areas of aquaculture, and in seaweed aquaculture in more developed regions of the country. These science-industry initiatives, such as those used by Sea Grant, provide farmers with an opportunity to work with researchers on research questions that they collaboratively identify, who provide their expertise to the investigation by providing funding and extensions services. Farmers can provide their lease, product or experience and benefit from participating in the research process. Sea Grant's extension professionals have

unique knowledge of the industry both within specific states, and across state lines. Their expertise lends itself to encouraging and facilitating a regulatory structure (i.e., environmental regulations, spatial planning, food safety, and best practices) to guide sustainable growth of the industry, an essential part of industry expansion (Cai et al. 2021).

The results of this needs assessment point to a chicken-and-egg problem that has also been identified in nascent seaweed industries in other geographies. There is interest in seaweed in many parts of the industry (e.g., growing, processing, and using in culinary preparation), but there continues to be a lack of consumer demand for consuming seaweed (Chambers et al. 2015). Cai et al. (2021) note that market demand was a driving force in increasing seaweed production in Scotland and Eastern Asia. Therefore, research into desired dishes and value-added seaweed products for a western palate (for example, Chambers et al. 2015), along with establishment of the nutritional benefits of seaweed consumption (Cherry et al. 2019) need to continue so that increased interest in consuming seaweed can drive expansion of the seaweed industry (Cai et al. 2021).

Finally, in alignment with other recommendations for this burgeoning industry, future efforts should strive to expand this industry into new markets at various levels (Grebe et al. 2019). While investigating increasing options for culinary and value-added seaweed products is one avenue to explore, investments in expanding options for using and processing seaweed in various ways should also be explored to assist in growing this potentially sustainable and valuable industry.

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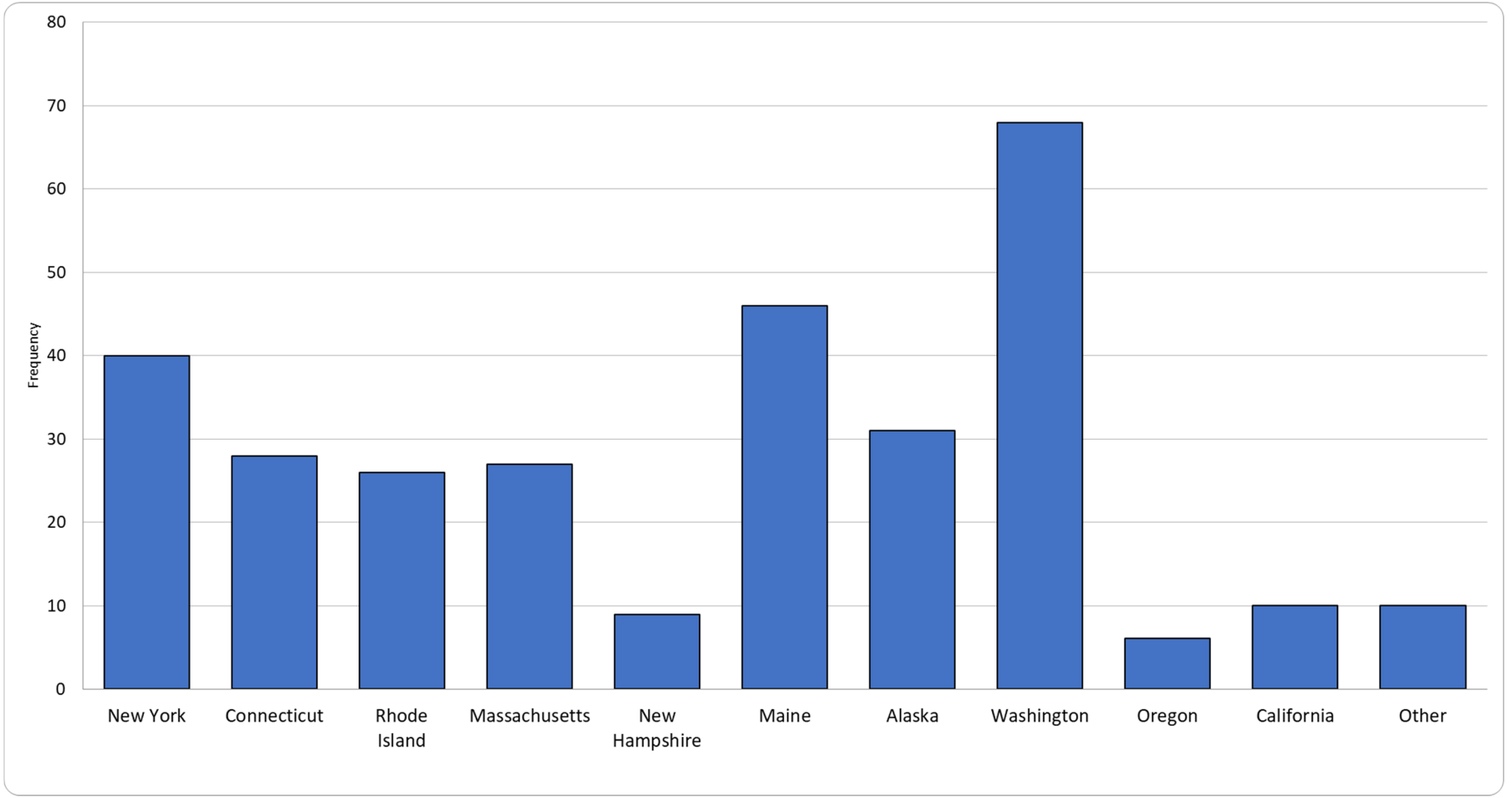
Figures

Figure 1. State Engagement in the Seaweed Industry (N = 301). Other responses included Hawai'i, Delaware and Missouri


80
70
60
50
40
30
20
10
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Frequency
New York
Connecticut
Rhode Island
Massachusetts
New Hampshire
Maine
Alaska
Washington
Oregon
California
Other

Figure 2. Role in seaweed industry by state (N = 479). Note: Number of responses is higher than respondents because responses regarding state and role are not mutually exclusive.

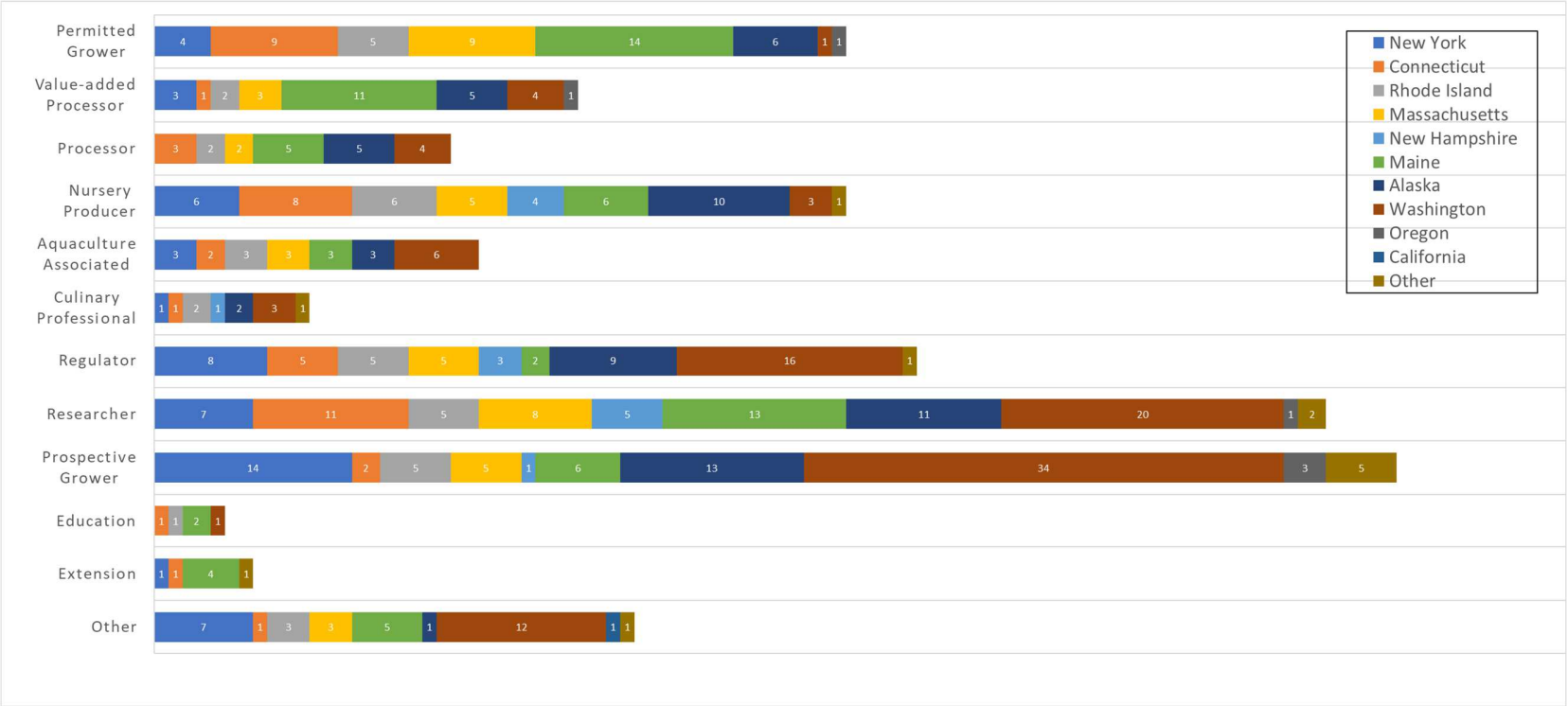


Figure 3. Percentage of seaweed sold by permitted growers by form (Total N=55; numbers in each section represent frequency).

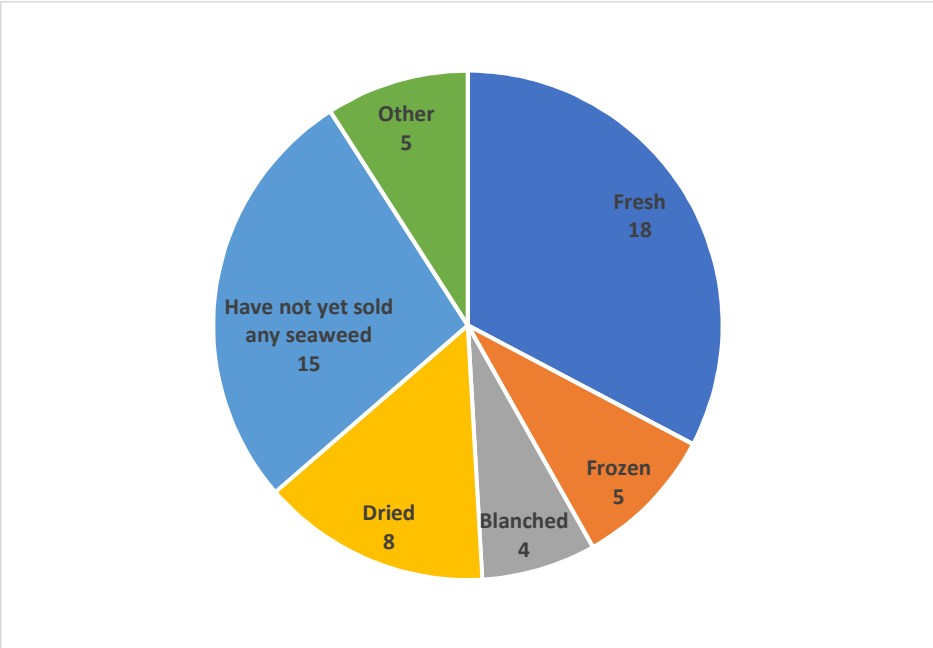


Figure 4. Industry challenges by group a) growers, b) processors, c) nurseries, and d) culinary professionals

Figure 4. Industry challenges by group: a) growers, b) processors, c) nurseries, and d) culinary professionals.

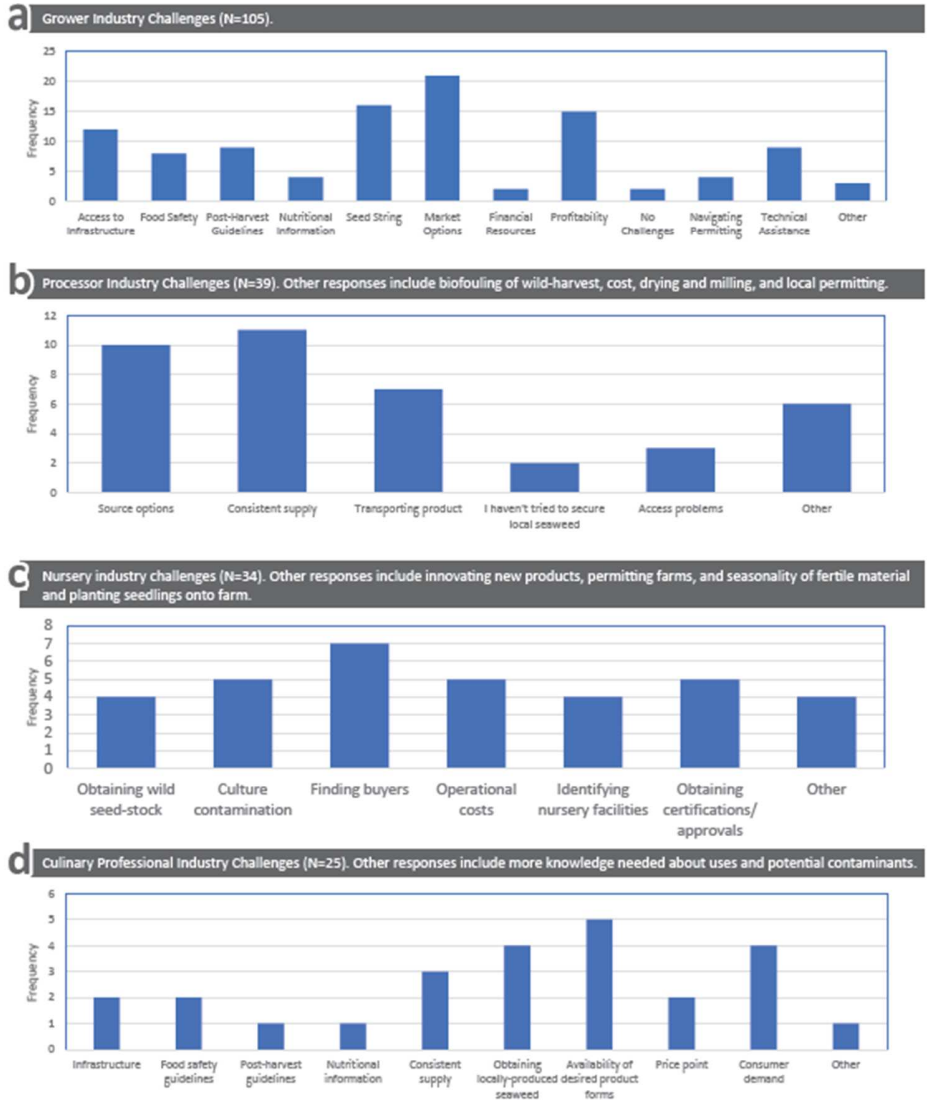


Figure 5. Industry challenges by group a) permitting regulators, b) public health/food safety regulators, c) prospective growers and d) researchers.

Figure 5. Industry challenges by group: a) permitting regulators, b) public health/food safety regulators, c)prospective growers, and d) researchers.

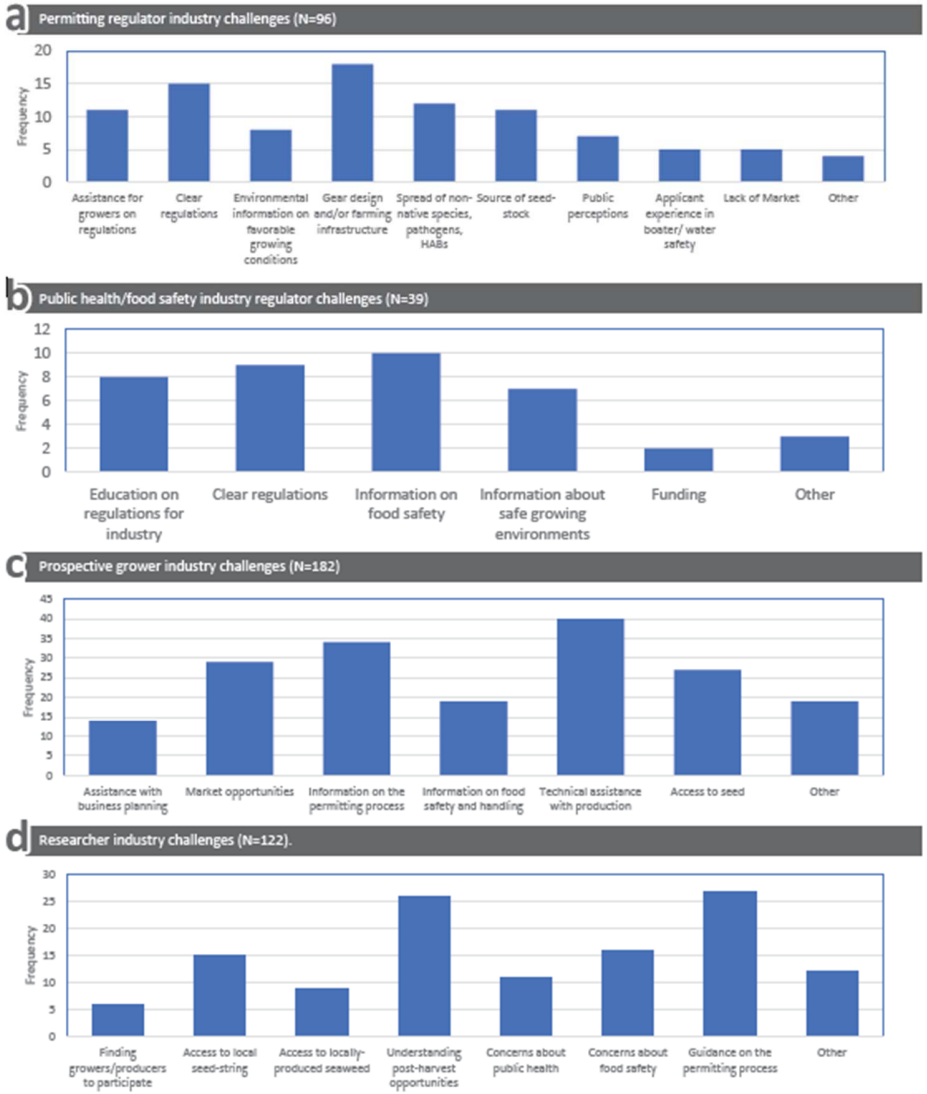
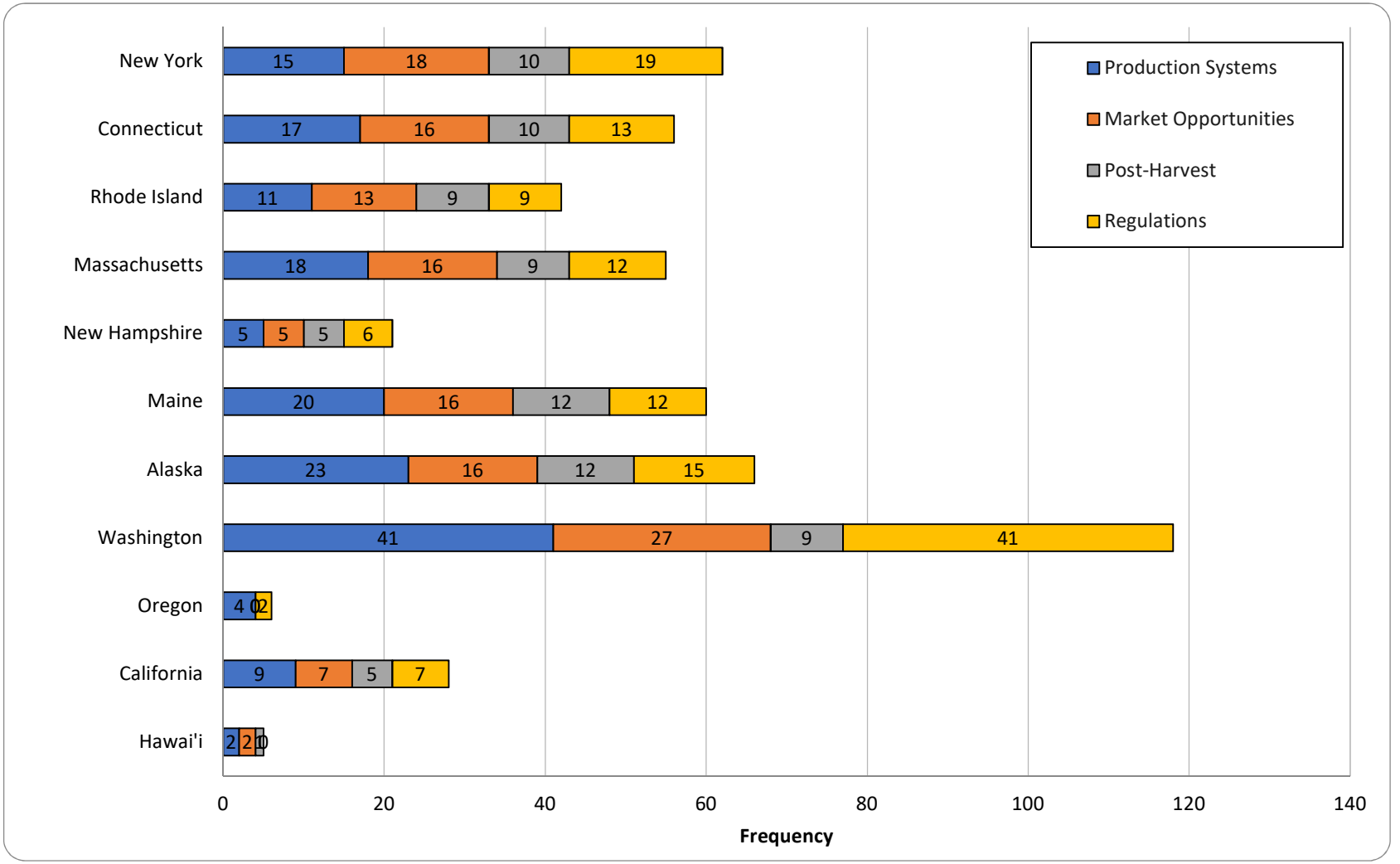


Figure 6. Overall industry challenges by State (N=519). Note: respondents selecting states other than those listed in the figure were not included.


New York
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Rhode Island
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Massachusetts
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New Hampshire
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Maine
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Alaska
23
16
12
15
Washington
41
27
9
41
Oregon
4
0
2
California
9
7
5
7
Hawai'i
2
2
0
Production Systems
Market Opportunities
Post-Harvest
Regulations
0
20
40
60
80
100
120
140
Frequency

Figure 7. Overall industry challenges by role (N=685). Note: since respondent roles and states of engagement are not mutually exclusive, the total frequencies reported for industry challenges differs between analysis by state and by role.