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ESTIMATING THE ECONOMIC BURDEN OF *VIBRIO PARAHAEMOLYTICUS* IN WASHINGTON STATE OYSTER AQUACULTURE: IMPLICATIONS FOR THE FUTURE

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ABSTRACT The bacterium *Vibrio parahaemolyticus* (Vp) causes gastrointestinal illness in people, generally through the consumption of undercooked or raw seafood. It is a major concern in the oyster industry, especially as the raw oyster market gains in popularity. As a result, a network of adaptive regulations is triggered during times when Vp risk is high (i.e., during warmer temperatures) and reporting requirements to track confirmed infections. A survey of three main stakeholder groups—managers, growers, and restaurants/retail locations—estimated the costs of these regulations for the Washington State oyster industry to quantify their economic burden. Study participants requested that these costs be categorized by actual dollars spent and labor hours needed, and then again by whether those expenses were part of Vp prevention efforts or as the result of a traceable illness. The survey revealed that prevention efforts cost an average $0.45 per dozen oysters landed and a traceable case costs an average of $61,880 for 2019. These costs are largely borne by growers in the form of fixed costs and therefore, there is also an economy of scale at play. The discussion then focuses on how these costs may apply to future management plans and farm budgets, as well as other geographies.

KEY WORDS: *Vibrio parahaemolyticus*, economics, food safety, regulatory burden

INTRODUCTION

The gram-negative halophilic bacterium *Vibrio parahaemolyticus* (Vp) has certain strains capable of pathogenicity in humans. It is naturally occurring and endemic to coastal waters across the globe. Infections from Vp typically cause self-limiting gastroenteritis, often from the consumption of raw or undercooked seafood. Whereas infections are often not life threatening, these bacteria are estimated to cause over 36,000 cases of foodborne illness each year in the United States (Scallan et al. 2011).

The association of Vp with the consumption of raw molluscan shellfish has been a persistent issue faced by industry, regulators, and public health officials. Molluscan shellfish sanitation in the United States is regulated under the National Shellfish Sanitation Program (NSSP), a cooperative arrangement between federal, state, and industry representatives recognized by both the Interstate Shellfish Sanitation Conference (ISSC) and US Food and Drug Administration. Standards are updated biennially, published, and implemented by the states (NSSP 2019). Whereas the NSSP covers all aspects of shellfish sanitation, control strategies for Vp are central to the program and required for states that have experienced an outbreak, had two or more illnesses in a 3-y period, or harvest during periods of elevated water temperatures. Temperature is a major driver of Vp growth with conditions exceeding 15°C generally considered suitable for growth. It is also capable of rapid growth, with generation times as short as 12–14 min at 37°C (Ulitzur 1974). Bacterial growth is particularly problematic postharvest, as oysters are not afforded the opportunity to purge when not in water. Thus, most control strategies focus on limiting potential for postharvest Vp growth through establishing time of day limits on harvest and/or time to reach 10°C through refrigeration. From the point of postharvest cooling through sale, a cold chain must be maintained. In the event of an illness associated with shellfish consumption, a cascade of events occurs to trace the source of the shellfish, which can in some cases lead to closure of harvest areas and product recall. Although necessary for the protection of public health, an underlying financial burden is incurred by both regulators in policy and enforcement and industry.

As a whole, the industry faces significant regulatory constraints (O'Connell 2018) and a challenging regulatory environment (Evrard 2017). In a survey gauging regulatory burden to the West Coast aquaculture industry, 19% of growers cited department of health regulations as their primary regulatory challenge (van Senten et al. 2020). The same study found the direct regulatory cost in Washington was $5.1 million annually ($241,000 per farm), with an additional $78.0 million annually ($1.7 million per farm) in lost sales as a result of regulation, and $97.4 million ($3.2 million per farm) as a result of lost opportunities for future sales growth. The smallest of these categories, regulatory costs, was further broken down by the type of regulation and food safety represented moderate annual costs at $218,997 for Washington, or $28,140 per farm. These costs scaled with size of farm, but per-hectare costs decreased with increasing farm size. The smallest small farms bore the largest proportional costs. These costs are part of determining an industry's competitive advantage in a global market, and should be considered relative to other trade jurisdictions in thinking about market potential.

For broader economic context, most studies put the total cost of foodborne illness in the United States at $5–10 billion as of 1999 (Antle 1999), and for Vp-caused illness at $20.63 million as of 2011 (Ralston et al. 2011). The benefits of implementing the Hazard Analysis Critical Control Point (HACCP) program were estimated at $0.99–$3.69 billion annually in 1995, whereas costs were $100 million annually in 1995 (Antle 1999). Another cost-benefit analysis found the 20-y present value of HACCP to be $2.2 billion (Macdonald & Crutchfield 1996). These costs, however, are further invested into the local economy, returning an additional $0.65 for each $1 spent to adhere to HACCP requirements (Golan et al. 2000). Looking at specific industries, pork farmers spend between $0.02 and $0.20

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per carcass on HACCP adherence (not including monitoring and testing); this number is kept small by the economy of scale of large processing plants, and represents 2% of packing costs (Jensen & Unnevehr 1999). California leafy green farmers spend $604,000 annually to comply with food safety standards, which increased by $210,000 after an *Escherichia coli* outbreak in 2006 (Ribera et al. 2012).

Washington State is the largest producer of cultured shellfish in the United States, with 23.4 million pounds in 2013 worth $92 million dockside value (WASG 2015). As such, the predicted and reported occurrence of annual Vp illnesses is higher in Washington State than in states with lower oyster production. The majority of states rely on rapid postharvest cooling and time to temperature restrictions as their primary Vp control measures. Washington has taken the additional step of designating risk for individual growing areas based on past illnesses occurrence (Table 1), with more stringent time temperature controls as risk category increases. The plan requires harvesters to monitor air and water temperatures at the time of harvest and establishes a tiered approach with varying timeframes during which harvesters are required to cool oysters following harvest. The time allowed between harvest and reaching cold storage is based on the assigned risk of the area and observed air and water temperatures, with lower temperature thresholds for the most stringent tiers in areas with a higher risk designation. Harvesters are also required to keep detailed records of harvest plans. In addition, the state maintains a surveillance program to examine Vp levels in oysters throughout the state, targeting sampling in high-risk areas in warm months. Combined, these factors make Washington the ideal state to begin to evaluate the economic burden of Vp.

The purpose of this study is to broadly determine the economic burden of current Vp regulations on the oyster industry and regulators in Washington State through first determining what types of expenditures are necessary to comply with Vp controls and meet NSSP mandates, and then asking industry members and managers about their experience with those expenditures. Motivations for the study include a desire to understand the cost of regulations, and to understand how these might shift with changing environmental conditions that may be more favorable to higher Vp risk. The ISSC mandates that economic burden (broadly defined) be considered in implementation of new requirements, yet numbers related to the cost of Vp controls are largely unavailable in the literature. As US coastal waters continue to warm, there is concern around increased risk of vibriosis and changes in geographic distribution globally (Paz et al. 2007, Baker-Austin et al. 2012, Jacobs et al. 2015, Muhling et al. 2017). Undoubtedly, regulations will change to keep pace with extended warm periods resulting in increased Vp risk or introduction of virulent strains to new areas. Foundational research on economic considerations will help quantify the costs of regulation that is necessary to inform trade-offs associated with new regulations and guide future decision-making processes and cost-benefit analysis.

TABLE 1.

Risk categorizations for shellfish growing areas in Washington in 2020.

Risk category	Definition: Annual cases	Number of growing areas
1	0.2 or fewer cases	81
2	0.3–1 cases	11
3	>1 cases	9

These are updated based on a 5-y rolling average each February by the WADOH, and specific area listings can be found on the website, https://www.doh.wa.gov/CommunityandEnvironment/Shellfish/CommercialShellfish/VibrioControlPlan/GrowingAreaRiskCategory.

METHODS

The economic model is based on a method developed by the United States Department of Agriculture for calculating the economic burden of food safety measures in the United States (Hoffman et al. 2015). Their approach uses an additive model that identifies costs at each step of the food production chain from farm to plate. To develop the conceptual model to identify each of these stepwise cost categories, a workshop was held at the Pacific Coast Shellfish Growers Association meeting in September 2018 in Blaine, WA. The workshop presented a draft list of costs based on the United States Department of Agriculture model, categorized by each major participant in the oyster production chain: growers, shippers, restaurants and retail facilities, and food safety managers. Growers and shippers were combined as a respondent category because most companies had a combined license from the state and costs were difficult to extricate across parts of the business.

The workshop was attended by approximately 40 people, including shellfish managers, growers, distributors, and researchers. Attendees informed the development of the model through a participatory conceptual model building exercise (Freitag et al. 2019) to add components to the model and restructure it according to their experience in the oyster industry in Washington and more recent regulatory changes to food safety practice. This conceptual model was used to create questions addressing each of the concepts identified in terms of associated cost and labor. Workshop attendees suggested a two-part model to be able to compare the costs of an ideal year (i.e., no cases reported) with the costs of a year in which a consumer gets sick with a Vp infection. Increased regulation decreases (but does not eliminate) the risk of illness; the financial tradeoff here depends on how much that risk is decreased.

Data collection occurred primarily through a phone-based structured interview with three main categories of respondents: managers, growers, and restaurants/retailers (OMB Control Number 0648–0787; see interview guides in supplementary materials). Because most growers in Washington State are also wholesale dealers, shipping and distribution costs are included in their responses. The study was a census of all industry members affected by Vp regulations. Contact information for growers, managers, and restaurants was provided by the Washington State Department of Health (WADOH). These included 189 growers that had reported oyster harvest in 2019, 28 restaurants and retailers that had a traceback investigation in 2019, and eight state, county, and tribal food safety managers who handle Vp inspections, illness tracebacks, training, and testing. Researchers contacted all potential participants via E-mail and phone up to 5 times: an initial E-mail, follow-up phone call,

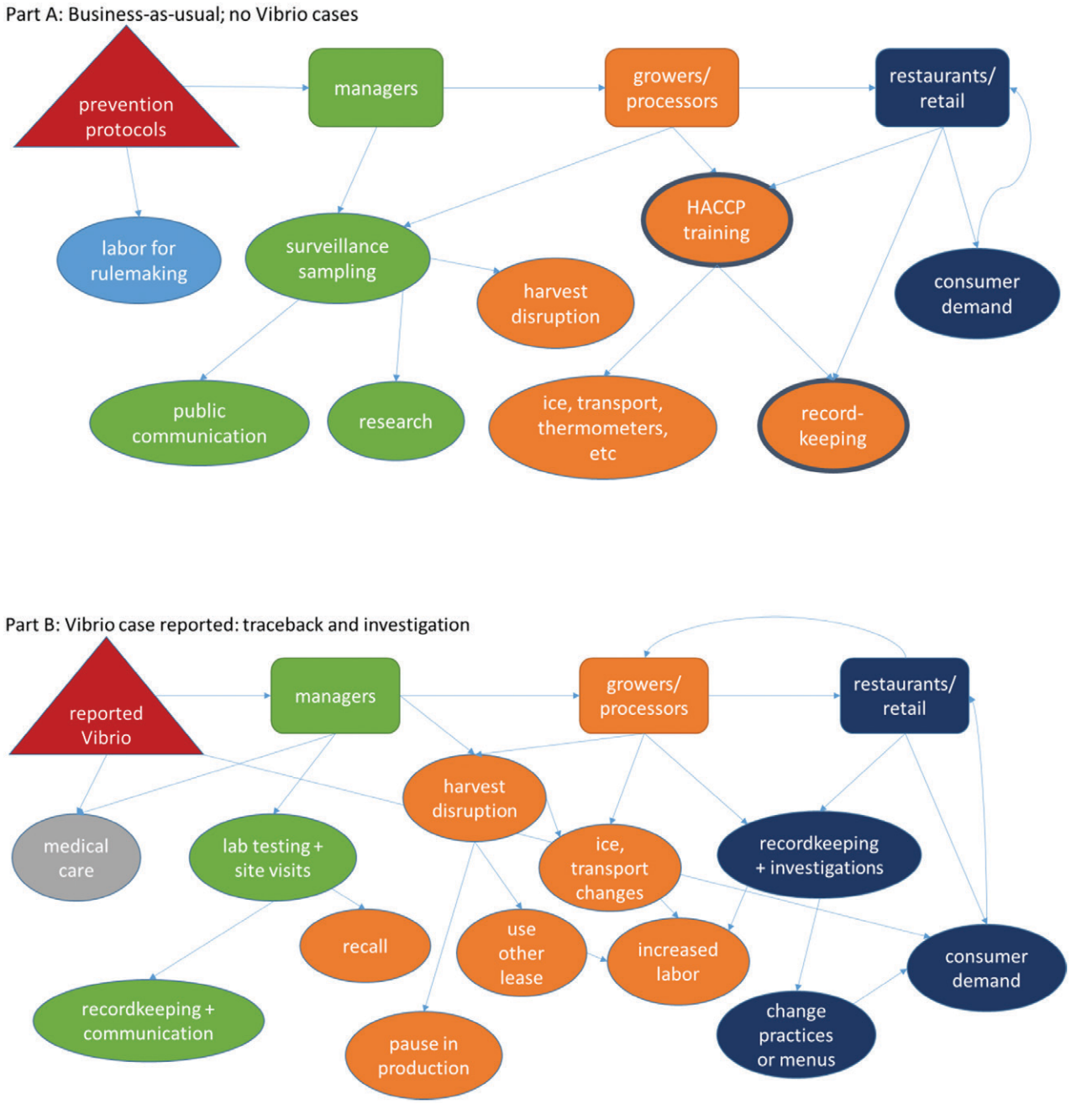

Figure 1. Conceptual model for costs associated with Vp management developed at a stakeholder workshop. Part A represents costs when no illness is reported, part B adds in costs associated with reacting to an illness. Boxes are color coded according to the stakeholder group responsible for the cost: green is managers, orange is growers/processors, and blue is restaurants/retail.

and reminder e-mail with the interview questions between April and June 2020 and with an e-mail and phone call in September 2020. The vast majority completed the interview over the phone, though some completed it via e-mail or had follow-up conversations via e-mail. Both English and Spanish options were available for participation.

Following the example of van Senten et al. (2020) and Roberts et al. (1996), the grower respondents were further stratified into groups based on farm size (acres) to account for economies of scale. The questions were divided into two sections according to the feedback in the workshop: surveillance/testing and traceback investigations. Questions solicited variable costs for 2019 (the last complete harvest year, and the period of time easiest for respondents to remember or find exact costs for) and fixed/capital costs since business establishment, scaled to modern dollars (Bradburn et al. 2004). Values for nonrespondents were imputed based on averages for each concept in the conceptual model for their strata. Labor hours were converted to dollar values using publicly listed salary ranges, and industry totals were calculated by adding all industry member values together.

TABLE 2.

Expenditures of the Vp management community.

	Hours	Non-labor costs ($)
DOH Vibrio staff	120/wk	0
Laboratory testing (May–September)	Included above	7,200/wk
Research/Policy	25/mo	1,000/y
Investigations	3/investigation	0
Communications and training	4/wk	0

Costs cover purchases beyond salary. DOH, Department of Health.

RESULTS

The conceptual model honed by stakeholders emphasized two possible pathways, each with different sets of costs: a situation in which Vp risk reduction measures are entirely successful and the only costs borne are for prevention (Fig. 1A), and another situation in which illnesses do occur and a public health response is activated (Fig. 1B). In the case of an illness, new costs are added into the first set of expenses. Workshop attendees expressed interest in the differential between the two pathways and stressed that although prevention does have recurring costs associated, it was a preferable state of business. Many categories are also collaborative efforts, with information, expertise, and equipment shared between groups to inform decision-making for Vp management, both to meet the regulations and to protect the reputation of the industry.

The survey, structured with questions centered around each of the nodes in the conceptual diagram, yielded an overall 46% response rate. The response rate varied by size strata, with 32% of small growers, 41% of extra small growers, 53% of medium growers, 56% of large growers, and 71% of subsistence growers. Response rate was consistent across the state, with representation from each of the major growing areas. Twenty of the growers were dropped from the respondent pool after closing permanently in 2020; this is a higher proportion than usual, but expected because surveys were administered in the summer of 2020 just after the strictest business shutdowns for the coronavirus pandemic had lifted. Nine growers also reported subcontracting their harvest to a larger company, and costs and acreage were reported for these in combination with that larger company.

Costs by Sector

The managers were the smallest group of respondents with a central point of contact and organizer in the form of a state shellfish food safety specialist. This position is nestled in a hierarchy of the food safety team at the WADOH, and relies upon the efforts of local inspectors and trainers in each county or tribe. Some of the tribes have an independent shellfish and/or food safety program that works in concert with the state agency, and the whole operation relies upon a central laboratory to analyze Vp levels in oyster samples. This laboratory is the largest cost from the management team, as the supplies are specialized and needed in large quantities for surveillance monitoring. Table 2 shows the cost breakdown across categories of expenditures for managers (total across the team), split into monetary and labor expenses (this presentation style will continue through the rest of this section, until means of converting labor hours to dollar values is presented).

Growers/shippers bore the largest costs of the respondent categories. Costs roughly scaled by the size of the operation, with the exception of subsistence farmers who invest more time and money into training for their many harvesters. These are largely tribal operations that grow for public harvesting, but are registered with the state as commercial growers. Costs for surveillance and training were minimal compared with equipment costs, but do represent a salary investment across many types of workers in the industry. This category of costs includes required training, participation in industry groups where Vp is on the agenda, and participation in the state surveillance program. Contributions were inconsistent across both geographies and time, and notably increased during farm expansions and when new staff came on board. Table 3 shows annual expenditures and labor time for each of the size categories.

The largest set of costs for growers was in equipment purchases to comply with the Vp regulations. Many growers/shippers reported they purchased equipment primarily for Vp, but in the process were able to protect against other foodborne illnesses; they stated although the costs should be attributed to Vp, it is impossible to completely extricate Vp expenses from food safety more generally. This lines up with regulatory timelines, where Vp was the primary concern for implementing food safety procedures and recognized earlier than other causes of foodborne illness. Note there is an economy of scale, where

TABLE 3.

Average annual costs and labor associated with surveillance and training per oyster grower.

Size class	Average dollars	Range ($)	Median ($)	Average hours	Range (Hours)	Median (Hours)
L (500 + acres)	1,837	22–4,900	13	171	2–606	24
M (100–500 acres)	226	0–789	57	44	8–108	30
S (10–100 acres)	182	5–953	21	44	2–307	11
XS (<10 acres)	119	0–1178	13	13	1–131	2
Subsistence	373	0–900	12	31	0–138	0.5

TABLE 4.

Average annual equipment expenditures, with capital expenditures, regular annual costs for maintenance, and decreases in harvest because of time requirements of Vp regulations.

Farm size	% less harvest	Range (%)	Median (%)	Average capital costs ($)	Range	Median ($)	Average annual costs ($)	Range	Median ($)
L (500 + acres)	17%	0–50	8	421,598	1,200–1,469,196	219,543	55,899	0–237,000	6,342
M (100–500 acres)	15%	0–50	5	51,892	5,000–94,833	53,867	6,953	150–11,613	8,025
S (10–100 acres)	6%	0–33	0	128,968	0–930,000	56,844	26,376	0–237,300	3,561
XS (<10 acres)	5%	0–90	0	29,464	0–417,000	1,931	4,704	0–55,690	857
Subsistence	7%	0–17	2	144	0–861	0	19	0–113	0

Range and median shown for each.

costs are largely proportional to the size of the company, and therefore the total costs should be considered alongside total revenues for interpretation as economic burden. The medium-scale companies deviated from this trend of an economy of scale, likely because the equipment purchases for small producers were enough to scale to a medium-size farm. All of the large farm respondents had a custom cooling system, tailored to their specific operation and location, installed with the purpose of handling large quantities of oysters. The other categories' respondents relied upon commercially available cooling systems including walk-in coolers, ice makers, commercial fishing totes, and refrigerated trucks. In addition, many respondents reported buying their equipment used or repurposing used gear to decrease capital expenditures, and this trend was especially prevalent among medium-scale growers. Finally, ice costs deserve some explicit discussion because ice is a small daily expenditure that added up to a significant amount over the course of a year, especially for extra small and small producers who buy bagged ice from a store. These producers may not have the capital at any one time to purchase an ice machine, even if it would save them money in the long-term; all of the medium and large growers had one or more ice machines. Finally, there is a nonmonetary cost of adhering to the Vp regulations and maintaining oyster temperature in the form of a less efficient harvest (see Table 4). Most producers reported a small drop in harvest efficiency because of Vp time and temperature rules that are implemented during warm temperature months.

Certain costs are only implemented if a Vp illness' source is traced back to the farm (Table 5). The vast majority of these traceback investigations involve record inspections and a phone call with WADOH staff and no actions needed as a result of the investigation. In very few cases, the investigation yields conclusive evidence that the Vp did come from a particular farm, either native to the water body the oysters were grown in or incubated by warm temperatures during handling. In these cases, the risk level of the water body may be increased (requiring additional protective measures and equipment), product harvested in the same batch as the illness-causing oyster may be recalled, or customers may not return. Attorney fees may be necessary and were included in the conceptual model by workshop attendees, though no one reported incurred fees in 2019. For all farms who reported participating in a traceback investigation, a "typical case" involved a simple WADOH investigation. Many of these investigations were inconclusive, as they were because of a multisource illness where a consumer ate a plate of oysters from many different places and subsequently fell ill. These typical cases have little cost associated with them. Some large costs, however, were incurred from the larger producers as a result of lost overseas customers, who evaluate the health and safety of the industry as a whole and not just the record of a single farm.

Restaurant staff identified costs that were above and beyond normal food safety practices because many more food safety requirements apply to restaurants than growers (Table 6). In addition, about half of the restaurants are part of a grower operation and leveraged the costs already incurred by the growers. These two trends led to small costs overall. In addition, most restaurants reported that growers reimbursed them for the costs of product implicated in a traceback investigation, so those costs are reflected in the grower costs. Customer impacts were also reported to be low or nonexistent across the

TABLE 5.

Average annual costs, labor, and lost harvest days associated with reported illness traceback investigations for growers.

Farm size	Average ($)	Range	Median ($)	Average hours	Range	Median (Hours)	Average harvest days lost	Range	Median (Days)
L (500 + acres)	100,241	0–300,000	0	14.7	0–40	0	12	0–35	0
M (100–500 acres)	50	0–200	0	5.5	3–10	4.5	0	0–0	0
S (10–100 acres)	5,143	0–36,000	0	42.5	0–274	0	6	0–28	0
XS (<10 acres)	7,257	0–50,000	0	24.6	0–160	0	10	0–45	0

TABLE 6.

Restaurant costs for both regular Vp prevention and traceback investigations, on an annual or per investigation basis.

Cost category	Costs	Range	Median
Training (cost)	$0/year	$0–0	0
Training (time)	29 h/year	0–200	0
Recordkeeping	138.84 h/year	12–364	130
Recordkeeping equipment	$24/year	$0–170	0
Other	$1379/year	$0–11,000	0
Investigation (time)	1 h/investigation	0.5–2	1
Lost product (cost)	$183/investigation	$0–550	0
Lost product (time)	0.1 h/investigation	0–0.25	0
Purchase changes	3% less revenue in high Vp years	0–15%	0

board, with respondents reporting that residents of the Pacific Northwest are both "tough" and aware of the risks associated with consuming raw oysters. This conclusion matches similar sentiments by the growers that international and domestic consumers react differently to reported Vp cases, with local consumers continuing to purchase oysters, whereas international customers decrease orders when Vp cases increase.

Some themes also emerged from the qualitative questions and from explanations of costs offered by respondents that might mediate the expenditures of a particular business or set of businesses. Most prominently, consistency is so valued that many growers reported following Vp protocols year-round such that the procedures were habit and in-place for the required warm weather months. Several mentioned that this protected them in times outside the official regulatory season (May–September) where waters might still be warm enough to present a Vp risk, such as the abnormally warm fall weather the region has seen the past few years. They followed these protocols even if it increased costs and labor. A related common theme is that most people considered the expenditures because of Vibrio minor, part of the cost of doing business, and for a good cause.

Another common theme for growers near deeper, cold water involved making use of the local environment rather than purchasing new equipment. For example, if there was a place near a grower facility to submerge the harvest in cold water, oysters were held there and directly loaded onto trucks or sold to consumers rather than using a walk-in cooler in a similar fashion. Similarly, producers spent intellectual labor that is not quantified to plan harvests in ways that reduce cooling equipment needs. For example, harvest from nearby beds might be saved for warm days to eliminate temperature management during boat transit or someone coordinates sharing of equipment across several nearby farms. Finally, the concept of community was important to many respondents. Some pointed at the importance of physical public infrastructure that their company made use of, such as working waterfronts with ice access. Many mentioned a responsibility to other growers in their growing area because the management risk category is determined by the cases traced back to the shared water body and is therefore determined by the behavior of everyone growing there.

Customer habits related to Vp risk were mentioned by both growers and restaurant staff, in the context of both their individual purchasing habits locally and the reputation of the industry, which drives demand in the global market. Lost reputation leading to decreased global sales represented a large portion of the case-related costs associated with Vp cases for the large growers. Total harvests in a given year are a product of industry capacity and consumer demand, with small fluctuations from year to year being driven largely by demand, as capacity is increasing (according to the number of growers registered and acres leased). A timeline of 2015 to 2019 shows that illnesses peak during warm summer months and had a high in 2018 even when considering the high landings that year (Fig. 2). According to DOH records, the following year, total landings were down, and of those that were landed, more were diverted to the shucked market, which does not pose a Vp risk as a result of additional processing the oysters receive. The peak was not considered newsworthy; this is reflected in the fact that Vp only appeared in one local news story (Beecher 2018), and that news coverage does not track with case load. This trend may relate to comments by respondents that Pacific Northwest residents are generally aware of Vp risk and choose to eat raw oysters anyways; decrease in demand likely came from export customers.

The costs borne by consumers in case of Vp illness are represented in medical care and borne largely by insurance companies. The literature on illness-associated medical costs divide expenditures into four types: no medicine, a doctor visit, hospitalization, or death. The vast majority of Vp cases require no medicine and therefore go largely unreported. Based on the rates across all four categories, the average cost per case is $2,543, based upon six estimates from the literature converted to 2019 dollars to match the period of time discussed with respondents (Archer & Kvenberg 1985, Todd 1989, Ralston et al. 2011, Hoffmann et al. 2012, Scharff 2012, Batz et al. 2014).

DISCUSSION

Statewide Estimates

Scaling up to the state level provides a single total estimate of costs based on current industry actors and current Vp case

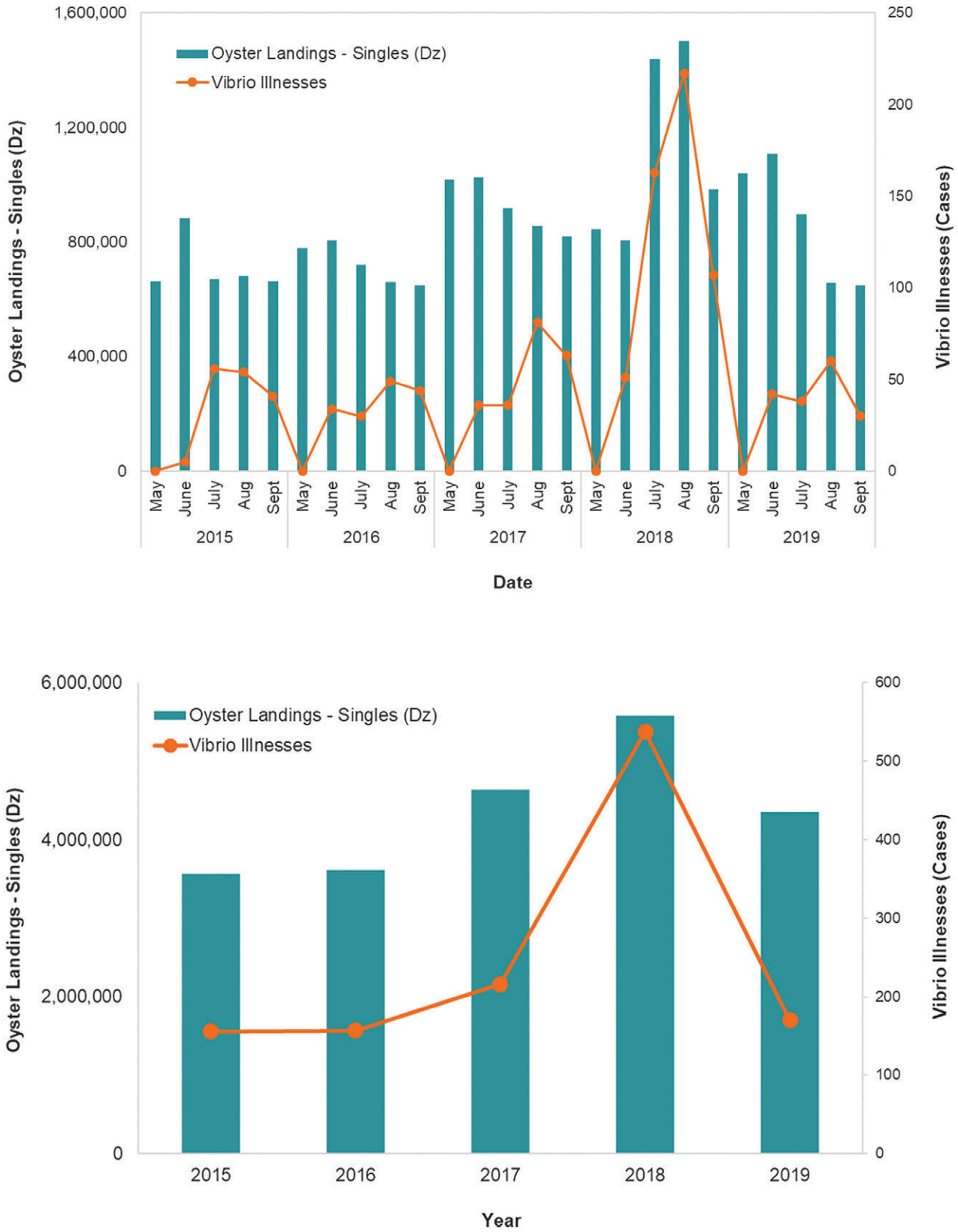

Figure 2. Oyster singles landings (dozens) and Vp illnesses (count of cases) during the summer months (May through September) of 2015 to 2019, shown by month (top panel) and by annual sum (bottom panel).

TABLE 7.

Annualized grower costs for 2019.

Category of cost	Dollars	Labor (Hours)	Total per dozen harvested ($)
Required trainings	8,742	1,673	0.0020
Conferences/optional trainings	24,573	3,134	0.0043
Surveillance testing	3,711	979	0.0011
7.11% less harvested	781,734		0.046
Equipment—capital (10%)	1,471,517		0.087
Equipment—annual	2,467,117		0.15
Case investigation	926,296	1,620	0.056
Case results: lost harvest days		3,216	0.0029
Total	5,683,690	10,622	0.349

rates (based on state records in 2019). Both of these factors are in flux depending on oyster demand, environmental conditions, market fluctuations for other fisheries in the region, current compliance with existing regulations, and many other factors. The statewide totals for cost category in each sector are the useful measurements for interpretation and translation to other years or other regions, scaled to the number of growers, production styles, and length of warm weather seasons.

Total management costs for 2019 were $242,320, using estimates of labor based on publicly listed salaries (http://fiscal.wa.gov/salaries.aspx) of $33.46 per hour. This comprises $2,811 for labor for case investigations and the majority of $239,509 for surveillance and prevention.

Total grower costs relied upon labor rate estimates from the Bureau of Labor Statistics for the median hourly wage for farmworkers/farm/ranch/aquaculture animals in Washington of $15.54. To convert the % less harvested as a result of Vp time and temperature restrictions into a value, a series of conversion factors were necessary to calculate 7.11% of total revenues. According to WADOH landings records, 6,678,042 dozen oysters were landed in May–September 2019, which at 0.378 meat lbs/dozen and $4.35/lb (converted to 2019 dollars from a Washington Sea Grant 2013 estimate of $3.96/lb (WASG 2015), yields $10,994,852 in Vp season revenue, and $16,955,903 for all of 2019. According to both equipment manufacturers and several respondents, capital costs are best annualized at 10% to account for depreciation and/or a regular replacement cycle. For case investigations that resulted in lost harvest days, catch was likely made up at a later time, but labor time was included, as workers spent that time in additional care and feeding of the oysters. With these conversion factors, the total annual cost for growers is $5,848,756. This represents $4,847,308 on surveillance and prevention and $1,001,447 on case investigations and response. There was an average number of 0.52 cases per year per farm, which can be assumed as an investigation every other year. Annual cost categories are provided in Table 7, and readers are encouraged to interpret these costs individually, as they will scale differently to different time periods or geographic areas.

Total restaurant costs were calculated using an estimate of 209 total seafood restaurants (Infogroup, Inc. 2012) and 28 investigations recorded by WADOH in 2019. A median hourly wage estimate of $14.60 for restaurant workers in Washington from the Bureau of Labor Statistics was used to convert labor time into dollar values. Consumer purchasing changes, which respondents reported at a loss of 3%, were quantified using the average sales per Washington Restaurant in 2018, $860,421 (NRA 2019). Restaurants spent a total of $1,535,057 in 2019, of which $806,686 was for surveillance and prevention and $728,370 was a result of Vp illness traced to the restaurant. For traceback costs, the vast majority of the costs are because of the reported loss of revenue after a Vp case, which relied on an industry-wide average revenue; this will vary widely by type and scale of restaurant.

The sum total for Washington State across the three contribution sectors that manage Vp in oysters was $7,626,133 in 2019. This is a year following a spike in Vp cases, where several growing areas had increased in risk category and concern over Vp was generally high. According to workshop attendees, a more useful way to break this down is by splitting it into the total costs for surveillance and prevention—$5,893,503—and for costs when an illness occurs—$1,732,630. Another way to look at these numbers and give them a sense of scale is by scaling the total cost across total harvest, which amounts to $0.45 per dozen oysters landed. It is critical to remember that this cost also covers other food safety concerns and requirements; whereas Vp was the motivator to put equipment and procedures in place, this action also protects growers from other foodborne illness concerns. The cost of illness, although the smaller portion of the overall expenditures, runs $61,880 per case and thus has the potential to drastically increase or decrease depending on caseload.

CONCLUSION

Although the results of this effort are specific to Washington State, a framework was provided for estimating costs in other areas and demonstrate that many components driving the economic burden of Vp may more generally be influenced by future climate change. Repeating this study in other areas would strengthen component cost estimates and lend insight into how to best generalize these results. Some of the largest costs come from equipment to keep harvest cold, which aid the

industry in a number of other ways; it is important to remember that most people found the costs minor if a bit logistically troublesome. Workshop participants were interested in the difference between prevention costs and case-associated costs. As caseload increases, resources needed for investigations will increase accordingly (at nearly $62,000 per case). More cases originating from the same water body will also increase surveillance and prevention costs the following year, as additional time and temperature restrictions are triggered with reported illnesses. Caseload is expected to increase and expand into more months of the year because of warming trends (Baker-Austin et al. 2012).

Fluctuations in the size and specialization of the oyster market will also drastically affect expenditures for Vp. Several producers reported switching from the raw market to shucked after an increase in local cases in 2018, which is evident in the WADOH harvest data as well; the area has available buyers for both markets, and processing for shucked oysters negates the need for extensive food safety protections on-farm, as they are pasteurized, frozen, or otherwise treated after shucking. Currently, a global pandemic stemming from a novel coronavirus has had a major impact on the economy. Growers reported coronavirus-related closures of restaurants (which sell the vast majority of raw oysters) temporarily shifted them toward the shucked market and drastically decreased overall sales. Aside from 2020, the trend is increasing popularity of raw oysters and oyster bars, so total cases should be expected to increase along with raw consumption (Botta et al. 2020). With increased demand worldwide for seafood, oysters, and raw oysters, the industry as a whole is expected to grow, and existing businesses may decide to scale up to meet the demand (Botta et al. 2020). While businesses moving from small- to medium scale may save money by taking advantage of an economy of scale, both brand new businesses and businesses scaling up from extra small to small or medium to large come with drastically increased overall costs (though these costs remain similar normalized to harvest size).

These costs should also be contextualized in a manager's laboratory budget or a business plan. For a laboratory budget, one of the biggest costs is in consumable laboratory supplies, especially reagents, and in staffing those laboratories. These costs will fluctuate with the caseload and the level of concern about Vp. For growers, although the costs were large, they are largely fixed. The Vp is serving as a motivation to purchase food safety equipment that benefits the farm in many other ways, including protections against other foodborne illnesses and a better tasting product derived from the same cold, salty water that protects against Vp. Without Vp, some if not all, of these expenses may have been undertaken anyway, just at a different time (yet, growers attributed them to Vp). Conversely, restaurants reported small incremental costs of Vp management because food safety requirements were in place before Vp regulations were enacted for the restaurant industry and direct costs because of illness were directly reimbursed by growers.

Overall, food safety protections of oysters, driven by Vp concerns, are more costly than those for pork, poultry, and vegetables, but still well worth the investment in protecting against costly illness (judging by the high potential cost of responding to an illness versus prevention costs). The costs are likely higher because of the distributed nature of the oyster industry, with many small producers each needing their own equipment without the advantage of an economy of scale. Even still, respondents repeatedly contextualized the expenses they described as minor over time and well worth the investment to protect the industry's reputation. There are also lessons to be learned from the medium-scale growers on how to keep costs down by sharing equipment, investing in ice machines, leveraging public working waterfronts, and making use of natural cool water that can help growers meet the increasing needs for Vp protection in the future. On the whole, though, members of the oyster industry pride themselves on safe products by limiting the likelihood of Vp in oysters, sometimes exceeding state regulatory requirements, and these costs are part of maintaining that excellent reputation.

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