



Commercial fishers' perceptions of jellyfish interference in the Northern California Current

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Jellyfish disruption of fisheries has been described in some coastal systems, but few thorough investigations have been conducted. To ascertain the economic impact and trend of jellyfish blooms in the Northern California Current (NCC), we mailed surveys to resident commercial shrimpers, salmon trollers, rockfish (blue, black), and groundfish fishers ($n = 872$). We asked fishers to estimate the damages caused by jellyfish—including costs of relocating to avoid blooms, lost fishing time, time lost to bycatch sorting, fish depreciation, and gear damage. Of the total respondents ($n = 111$), 67% reported that jellyfish reduce their seasonal revenue, but the degree of impact ranged considerably by fishery and location. Highest jellyfish nuisance corresponded to regions with the most salmon trolling effort. Using the mean revenue losses provided by respondents, we estimate that the combined economic impact of jellyfish on Oregon's salmon and pink shrimp fishers was over \$650 000 in peak jellyfish season (June–September) in 2012. Fishers reported that jellyfish biomass varies annually, but most respondents (51%) reported observing no appreciable change in jellyfish populations in the last 5 years. Since economic impact analyses have been conducted primarily in areas with anomalous, high-density blooms, data from the NCC, which is not known to be experiencing increases in jellyfish abundance, provides baseline information on the socio-economic impact of jellyfish blooms in this region. In addition, the finding that jellyfish impact hook and line fisheries—not solely net fisheries—has implications for many other regions where fishers employ this gear type.

Keywords: *Chrysaora fuscescens*, commercial fishing, fishers' opinions, jellyfish, jellyfish blooms, salmon.

Introduction

Despite a number of studies documenting the prevalence of jellyfish blooms and their ecological impacts (e.g. Brodeur *et al.*, 2002; Graham *et al.*, 2003; Baxter *et al.*, 2011), the socio-economic consequences of blooms are not as well studied (Gibbons and Richardson, 2013). The studies that have investigated economic factors, however, suggest that jellyfish can impose considerable economic damage upon coastal industry (e.g. Seshadri *et al.*, 2000; Purcell *et al.*, 2007; Hay and Murray, 2008), tourism (e.g. Harrison *et al.*, 2004; Baumann and Schernewski, 2012; Kontogianni and Emmanouilides, 2014), and fisheries (e.g. Bämstedt *et al.*, 1998; Nagata *et al.*, 2009; Kim *et al.*, 2012; Quiñones *et al.*, 2012; Nastav *et al.*, 2013). As human activity in coastal systems increases, jellyfish interference may intensify regardless of whether jellyfish populations are increasing compared with historical levels. Because of this, an understanding of how jellyfish interact with human activities will be

increasingly important to complement the scientific investigation of long-term population trends (e.g. Gibbons and Richardson, 2013).

Identifying the consequences of jellyfish blooms on various sectors is a prerequisite to managing bloom impacts. Localized jellyfish population increases can substantially disrupt local fisheries by forcing vessels to relocate, by inconveniencing fishers when they retrieve their harvest, or by causing painful stings to fishers. Depending on the fishery, the damages can take other forms, including fouling gear, bursting nets, stinging captured fish and spoiling their commercial value, or increasing the sorting time of bycatch. In Japan, for example, blooms of *Nemopilema nomurai* clogged and burst the set-nets of fishers along almost the entire Japanese coast in the early 2000s, eliciting complaints from more than 100 000 commercial fishers (Uye, 2008). The economic impacts of jellyfish interference can be severe—the spotted jellyfish *Phyllorhiza*

punctata has been estimated to cost the shrimp industry in the Gulf of Mexico millions of dollars (Graham *et al.*, 2003; Richardson *et al.*, 2009).

Neither the ecological impacts nor socio-economic consequences of jellyfish are well understood in the Northern California Current (NCC) system. Yearly, blooms of scyphozoan jellyfish in the NCC reach highest numbers in summer. On an interannual basis, abundance is positively correlated with the cool phase of the Pacific Decadal Oscillation, as well as higher salinities during summer due to reduced input from the Columbia River (Suchman *et al.*, 2012). A recent time-series analysis of zooplankton community interactions in the NCC shows that climate variables, including sea temperature and decadal-scale climate indices (*El Niño* Southern Oscillation) influence both abundance and trophic interactions among zooplankton groups (Francis *et al.*, 2012). Scyphomedusae biomass in this region is dominated primarily by two species (*Chrysaora fuscescens* and *Aurelia labiata*; Brodeur *et al.*, 2008). *Chrysaora fuscescens* is the more abundant of the two, whose blooms reach the greatest density (Suchman and Brodeur, 2005). Biomass of *C. fuscescens* in the NCC reached 50 mg C m⁻³ in 1981, 64 mg C m⁻³ in 2001, and 28 mg C m⁻³ in 2002 (Shenker, 1984; Suchman and Brodeur, 2005). Comparatively, densities of blooms of *N. nomurai* that burst the nets of Japanese fishers were 40.5 mg C m⁻³ (Uye, 2008; Lucas *et al.*, 2011). In addition to their abundance, *C. fuscescens* and *A. labiata* also have considerable spatial and dietary overlap with many species of commercially important planktivorous, pelagic fish (Brodeur *et al.*, 2008).

Commercial fisheries in the NCC support 125 communities in California, Oregon, and Washington, annually contributing over \$28 billion in seafood sales (Sepez *et al.*, 2006; National Marine Fisheries Service, 2009). The continental shelf sustains groundfish, salmon (*Oncorhynchus tshawytscha* and *Oncorhynchus kisutch*), sardine (*Sardinops sagax*), and mackerel (*Trachurus symmetricus* and *Scomber japonicus*) fisheries, as well as much of the Pacific whiting (*Merluccius productus*) fishery (Field *et al.*, 2006). Salmon trolling—for both Chinook and coho—has high spatial overlap with the distribution of *C. fuscescens* since both populations occupy surface waters within the inner shelf and are associated with cold upwelled waters (Brodeur *et al.*, 2008). The North American commercial salmon fishery is forecasted to experience significant economic distress in coming years (Noakes and Beamish, 2011). More generally, all commercial fishers face the economic pressures of increased fuel costs, annual boat depreciation, variable operating costs, and landings value (Sumaila *et al.*, 2008; Lam *et al.*, 2011), and jellyfish have the potential to further increase the cost of fishing effort.

A growing body of literature indicates the potential for fishers' local ecological knowledge (LEK) to improve scientific research and resource management (e.g. Mackinson and Nottestad, 1998; Huntington, 2000; Johannes *et al.*, 2000; Silvano and Valbo-Jørgensen, 2008). Fishers may offer a rich source of ecological information acquired from field observations, intuitions, and experiences. In particular, fishers are known to closely observe environmental features that are linked to fishing success (Mackinson and Nottestad, 1998). Jellyfish blooms may be one such feature, since they are known to affect fishing success in other regions (e.g. Uye, 2008). Gibbons and Richardson (2013) recognized that diverse and unconventional data sources, such as fishers' local knowledge, will be necessary to contextualize and quantify jellyfish blooms. Like other forms of knowledge, LEK can sometimes contain incorrect inferences or erroneous conclusions, and may be informed

by culturally based values or personal opinions (Huntington, 2000; Usher, 2000). The utility of LEK, however, has been well documented for increasing the effectiveness of management by involving the resource users in decisions that affect them (Huntington, 2000). This may be particularly true for the NCC, a region where commercial fishers are reported to feel insufficiently represented in the management process (Conway *et al.*, 2002). The judicious use of informal data sources such as LEK may help bridge research and management, and may also provide a valuable perspective on the ecology and temporal abundance of a species (e.g. Johannes *et al.*, 2000; Dulvy *et al.*, 2004; Rochet *et al.*, 2008; Thornton and Scheer, 2012). A survey of French fishers in the eastern English Channel, for example, showed fishers perceived the time frames of environmental changes with reasonable accuracy, detecting both long-term and short-term population trends (Rochet *et al.*, 2008). Moreover, combining local knowledge with scientific information sources can lead to novel insights or outcomes (Mackinson and Nottestad, 1998).

In the present study, we mailed questionnaires to commercial fishers in various types of fisheries in the NCC to investigate their perceptions of jellyfish interference. Our specific objectives were the following: to qualitatively describe the nature of jellyfish interference with commercial fishing activity and how interference varies by fishery; to evaluate fishers' perceptions of the severity of jellyfish nuisance in this region; to semi-quantitatively approximate the magnitude of economic damages caused to fishers by jellyfish; to understand fishers' perceptions of jellyfish ecology (i.e. spatial distributions and population trends); and to spatially relate fishers' perception of jellyfish nuisance to scientific data on jellyfish abundance and fishing effort. These objectives align with the recent call for the research community to refocus its attention on understanding the implications of jellyfish blooms and managing them (Gibbons and Richardson, 2013). Since commercial fishers are a primary stakeholder group affected by jellyfish blooms, their perceptions of the issue are essential to defining efficient mitigation and management schemes (e.g. Salas and Gaertner, 2004).

Material and methods

Data collection

On 25 September 2012, we mailed questionnaires to resident commercial shrimpers, salmon trollers, and rockfish (blue, black) fishers registered in the Oregon Department of Fish and Wildlife database of permit holders ($n = 761$), and groundfish limited-entry permit holders registered in the Northwest Pacific Management Council database ($n = 131$; Table 1). All respondents were provided with a stamped and addressed return envelope. Additional, follow-up mailings were not conducted due to limited resources.

Identifying forms of jellyfish interference with commercial fishing activity

The nuisance level of jellyfish on fishing activity and the frequency and severity of jellyfish stings were evaluated using multiple different ranking questions (e.g. Q: "How much of a nuisance are jellyfish to your fishing activity?" A: "No nuisance; Mild nuisance; Moderate nuisance; Moderate-severe nuisance; Severe nuisance"; Table 1; questions 4, 11, 12). Fishers were also asked to fill in blanks with estimates of the economic losses of the various different forms of jellyfish interference (Table 1; questions 5 and 6). In an attempt to account for differences in average revenue between vessels, cost estimates were requested both as an absolute value and as a percentage

Table 1. Form of mailed questionnaire.

Survey question	Question type
1. Of the fishing gears you use, please write the one gear type for which you experience the most problems with jellyfish. If jellyfish never pose a nuisance to you, check N/A	Fill-in-the-blank
2. Between June and September, what species of jellyfish pose the greatest nuisance to you? (<i>You may check more than one, or none, if jellyfish do not pose any nuisance to you</i>)	Multiple choice
3. Please select the general area(s) where you do the most of your fishing	Multiple choice. Options from a defined list of regions based on coastal promontories
4. How much of a nuisance are jellyfish to your fishing activity?	Likert scale
5. Between June through September, do swarms of jellyfish increase your expenses/reduce your revenue? If yes, how?	Multiple choice. Options: Fishing must be relocated to avoid jellyfish swarms; Fishing time must be shortened because of jellyfish swarms; Jellyfish bycatch increases sorting time; Jellyfish sting captured young fish, which spoils their commercial value; Jellyfish foul/wreck gear; Other; please explain; No, jellyfish do not reduce my revenue from fishing
6. If you answered "yes" to the previous question, please approximate how much revenue you lost between June and September 2012 as a result of the following	Fill-in-the-blank. Options provided correspond to those in the previous question, e.g.: Relocating to avoid jellyfish swarms: \$ _____ Shortening fishing time because of jellyfish swarms: \$ _____
7. What percentage of your seasonal revenue, between June and September, do the cumulative losses from jellyfish represent?	Rating scale (0%, ~1%, ~5%, ~10%, Other, fill-in-the-blank)
8. Was this past season (June–September 2012) a typical season regarding the impact of jellyfish on your fishing?	Multiple choice; options: Yes, this season represents an average impact; No, last season I incurred more losses; No, last season I incurred fewer losses; I never incur economic losses because of jellyfish
9. Indicate your level of agreement with the following statement: "I see more jellyfish during my fishing now than I did 5 years ago"	Likert scale
10. To the best of your recollection, in what year do you remember you observed the most jellyfish during your fishing?	Fill-in-the-blank
11. Between June and September, how often are you typically stung by jellyfish while fishing?	Rating scale (never, daily, weekly, monthly, once every few months)
12. If you have been stung by jellyfish while fishing, how painful are the stings?	Likert scale
13. If you have any additional comments or opinions about any of the above topics or the survey itself, please share them here	Comment/essay box

of seasonal revenue. Economic impacts were then calculated from the values provided by respondents. Qualitative estimates such as "small amount" ($n = 4$), "no problem this year" ($n = 3$), and "unknown" ($n = 30$) were omitted from analyses. An implicit assumption of this method of estimating economic impacts is that fishers' perceptions of costs due to jellyfish interference reflect actual costs incurred.

Fishers were asked to identify jellyfish to species-level in a multiple-response question using colour photographs for reference (Table 1; question 2). Medusae selected for inclusion in the survey (*Aequorea* sp., *A. labiata*, *C. fuscescens*, *Cyanea capillata*, *Phacellophora camtschatica*, and *Veleva veleva*) were selected based on their large size and known abundance in the study region (Suchman and Brodeur, 2005; Suchman et al., 2012). To analyse the nuisance level associated with different jellyfish species, the nuisance level reported by each respondent (Table 1; question 4) was assigned to each of the one or more species indicated in the multiple-response question (Table 1; question 2).

Determining spatial patterns of jellyfish interference with commercial fishing activity

To assess nuisance level by fishing location, fishing regions off the coast of Oregon were divided based on coastline promontories (e.g. Columbia River to Cape Falcon; Cape Arago to Cape Blanco; Figure 1b). Areas outside of Oregon were more broadly considered

as "North of Columbia River" and "South of Oregon". Some respondents reported fishing in a localized area (e.g. Winchester Bay), while others reported fishing the entire coastline. Since *C. fuscescens* is the most abundant medusa off the Oregon coast (Suchman and Brodeur, 2005), fishers' perceptions of jellyfish abundance and distributions were compared with published data on summertime distribution of *C. fuscescens* (Ruzicka et al., 2007; Figure 1a).

To examine the relationship between reported jellyfish nuisance and fishing effort, we used a dataset of aggregate fishing effort collected by Project CROOS (Collaborative Research on Oregon Ocean Salmon), a cooperative research effort between scientists and over 150 contracted salmon fishers (<http://projectcroos.com/>). The overall distribution of sampling effort by the Project CROOS participants approximately reflects the areas fished by the commercial salmon trolling fleet (P. Lawson, pers. comm.).

Identifying fishers' perception of jellyfish population trends

Survey techniques included Likert scale questions, in which we asked fishers to indicate degrees of support for or opposition to statements such as "I see more jellyfish during my fishing now than I did five years ago" (Table 1; question 9). To evaluate perceptions of longer term population dynamics, fishers were asked to provide the year in which they recalled maximum jellyfish

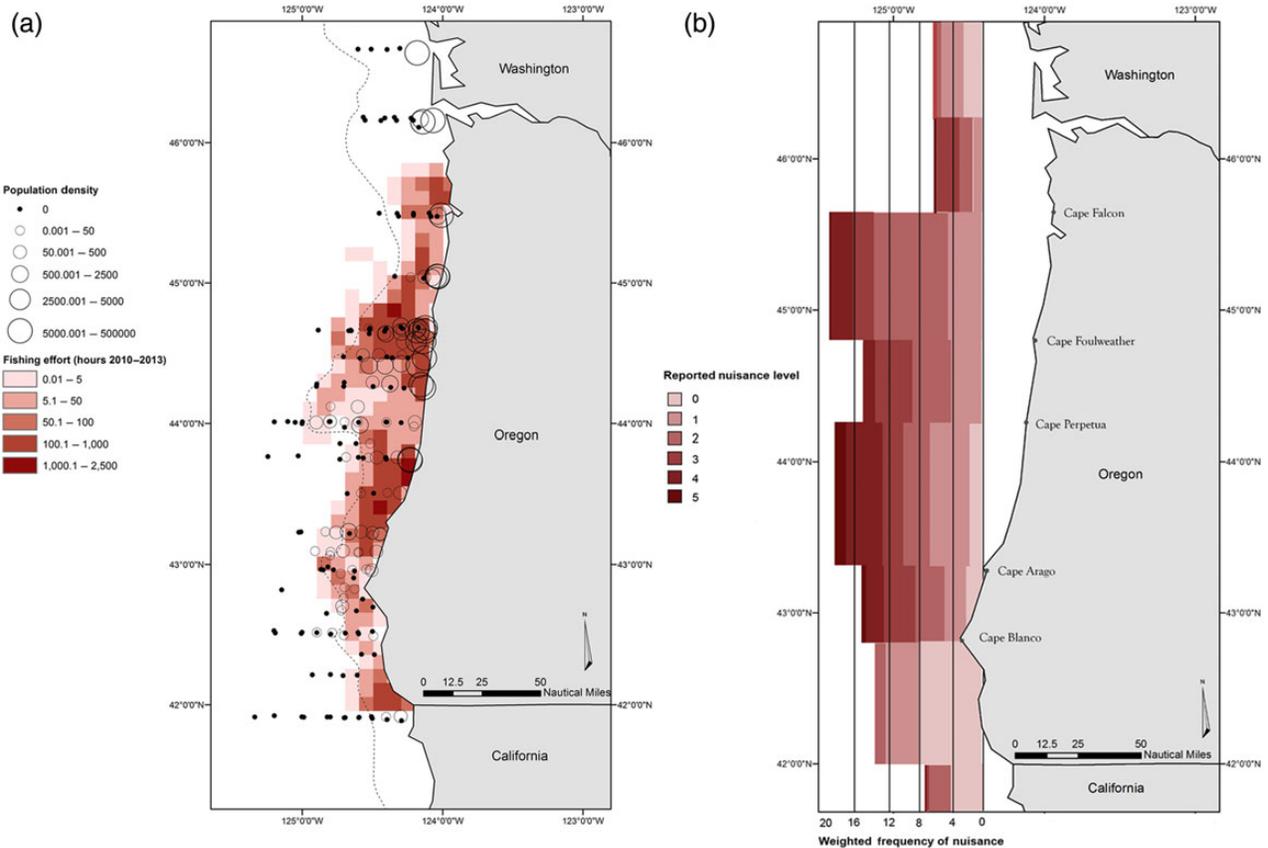


Figure 1. (a) Bubble plot of distribution of *C. fuscescens* off the Oregon coast during summer (July–September) of 2000 and 2002 (years pooled) overlaid on heat map of fishing effort (hours) of Project CROOS salmon fishers from 2010 to 2013. Distribution data modified from Ruzicka *et al.* (2007). Line indicates 200 m isobath. (b) Frequency and nuisance level of jellyfish to commercial fishers. Oregon fishing regions are divided based on physical promontories of the coastline (e.g. Cape Blanco to Cape Arago constitutes one region) and data from Washington and California are examined at the state-scale. These regional divisions only consider fishers' latitude, not longitude. The x-axis shows the frequency of responses, weighted according to the number of regions in which fishers reported fishing.

abundance (Table 1; question 10). Respondents who reported a range of years (e.g. 2005–2007) were assigned to the closest corresponding decade (e.g. 2010s). One respondent who reported high abundance in *El Niño* years was excluded from analysis. Three respondents reported two different years in different decades, and each of these responses was counted separately, for a total of 53 observations. Data were also presented in decadal bins because of evidence that jellyfish populations fluctuate decadally (Condon *et al.*, 2013), and also in individual years, wherein years reported as a range (e.g. 1980s; mid-1980s; late 1970s) were assigned an approximate year (e.g. 1980; 1985; 1979). The questionnaire did not ask about respondents' ages, and so this method does not account for the varying ages of respondents. The results may therefore be biased towards observations of high abundance in more recent years because more respondents presumably fished during that time.

Data analysis

We used a weighting system according to how many regions fishers reported fishing (Table 1; question 3) to equalize the weight of the answers in the analysis (Nagata *et al.*, 2009). Each answer was assigned a weight of 1, and this value was divided by the total locations indicated in the survey. Thus, when only one fishing location

was reported, a weight of 1 was attributed to this response; when two locations were reported, the weight was 0.5, etc. This method assumes spatial homogeneity of nuisance level across the respondents' respective fishing area(s). The maximum number of locations indicated was eight (constituting the entire coastline from Washington to California).

Fishing effort data collected by Project CROOS were provided in cell sizes of $0.01 \times 0.01^\circ$ of latitude and longitude to protect the privacy of the Project CROOS fishers. The latitude and longitudes were averaged to generate a midpoint of each cell. Midpoints were converted to raster format (0.1 cell size), and clipped to portray the nearshore area of interest (ArcGIS v10.2). Effort reflects the sum of the number of records from that grid cell between 2010 and 2013.

Results

Forms of jellyfish interference with commercial fishing activity

We received 111 survey responses, representing fishers across the Pacific region of North America, but Oregon salmon trollers provided most responses (Table 2). The response rate and non-response bias that this represents are difficult to calculate because many fishers hold permits for multiple fisheries (i.e. the number of NCC fishers is smaller than the number of permit-holders in the databases

Table 2. Jellyfish impacts on different fishing gear types in the NCC.

Gear type	Jellyfish species that pose nuisance (in ranked order)	Respondents reporting financial losses from jellyfish (% of total respondents)	Seasonal revenue loss per fisher 2012 ($\bar{x} \pm \text{std. error}$)	Percentage seasonal revenue loss in high jellyfish years ($\bar{x} \pm \text{std. error}$)	Percentage seasonal revenue loss in low jellyfish years ($\bar{x} \pm \text{std. error}$)	Predominant form of impact (number of reports)	Summary of jellyfish interference
Salmon/tuna troll (n = 83)	<i>Chrysaora fuscescens</i> , <i>Cy. capillata</i> , <i>A. labiata</i> , <i>Aequorea</i> sp., <i>P. camtschatica</i> , <i>Pe. periphylla</i>	61.45%	\$1 030 \pm 289	5.18 \pm 0.74	1.53 \pm 0.29	Foul gear (49); relocate (34); reduce catch (15); shorten fishing time (8)	Jellyfish snare on hooks and tackle (lead ball snubbers, jigs, hoochies, flashers). More labour to keep gear clean. Salmon less inclined to bite fouled gear. Trollers pull their gear, clean off the jelly material, reset gear. Greatest problem for trollers inside 25 fathoms, constraining nearshore fishing
Pink shrimp trawl (n = 9)	<i>Aequorea</i> sp., <i>A. labiata</i> , <i>Velevella</i> <i>velevella</i>	55.55%	\$5 222 \pm 2 252	3.0 \pm 1.15	0.89 \pm 0.54	Relocate reduce vessel speed and catch shorten fishing time	Jellies prevent water from flowing through the web, stretching the web and ribline. Net fails to catch shrimp
Rockfish hook and line (n = 12)	<i>Chrysaora fuscescens</i>	16.66%	\$88 \pm 83	2.92 \pm 1.79	0.92 \pm 0.83	Foul gear (2); reduce catch (2); relocate (1); shorten fishing time (1)	Low effect on income but may reduce fish catch if jelly material ensnares on hooks. May affect live fish fishery by reducing survival of catch
Groundfish trawl (n = 6)	<i>Chrysaora fuscescens</i>	16.66%	\$231 \pm 250	0.83 \pm 0.83	0.17 \pm 0.17	Relocate (1); shorten fishing time (1); foul gear (1); bycatch increases sorting time (1); changes fishing practices (1)	Relocate; reduce vessel speed and catch; shorten fishing time
Crab pots (n = 13)	<i>Chrysaora fuscescens</i> , <i>A. labiata</i> , <i>V. velevella</i> , <i>Cy. capillata</i>	N/A	N/A	N/A	N/A	Stung (5); stung in eyes (4); foul pot lines when retrieving (6); relocate (3)	Reportedly low economic impact, but sometimes caught in crab pots and broken apart in cage mesh. Crabbers reeling in pots occasionally get tentacles flung into face, eyes, causing severe, prolonged stings
Sardine seine (n = 1)	<i>Aurelia labiata</i>	100%	Unknown	15.0 \pm 0.0	0.0 \pm 0.0	Relocate (1)	Relocate to avoid blooms in past years, but not 2012

Because fishers were allowed to select multiple species of nuisance jellyfish and multiple forms of jellyfish impact, *n*-values for these columns include double-counts and therefore may total to more than the total respondents for that gear type.

used to send questionnaires). The 12% response rate is therefore an underestimate, and the non-response bias is < 88%.

Results from the surveys indicated considerable differences in nuisance and economic impact from jellyfish among fisheries (Table 2), but some commonalities existed across gear types. Fishers frequently reported that while jellyfish do pose a nuisance to their fishing and often increase their workload, it is extremely hard to quantify a revenue loss for many of the ways jellyfish force fishers to modify their work (Table 1; question 13). Eighteen per cent of respondents reported never having thought about jellyfish as a form of revenue loss, but noted that jellyfish did increase labour. Most respondents (79%) reported that jellyfish were a nuisance to their fishing activity and 67% reported that this nuisance reduced their revenue. Observations of nuisance were often qualified

by recognition of jellyfish as a part of the ecosystem (e.g. "... [I] always accept them as part of [the] overall experience" or "[Jellyfish are a] natural course of nature") (Table 1; question 13).

Eighty-four per cent of respondents who reported that jellyfish were a nuisance ($n = 88$) were able to identify the jellyfish to species-level using the colour photographs provided in the mailed survey. The species predominantly responsible for these losses was *C. fuscescens*, followed by *Aequorea* sp., but different species accounted for nuisance across the different fisheries (Figure 2). *Chrysaora fuscescens* was the species associated with the greatest frequency of high-nuisance (≥ 3 on a 1-to-5 ranking scale ranging from no pain to very severe pain) reports.

Fishers revealed that the social impacts of jellyfish tend to be minimal compared with economic ones: the majority (48%)

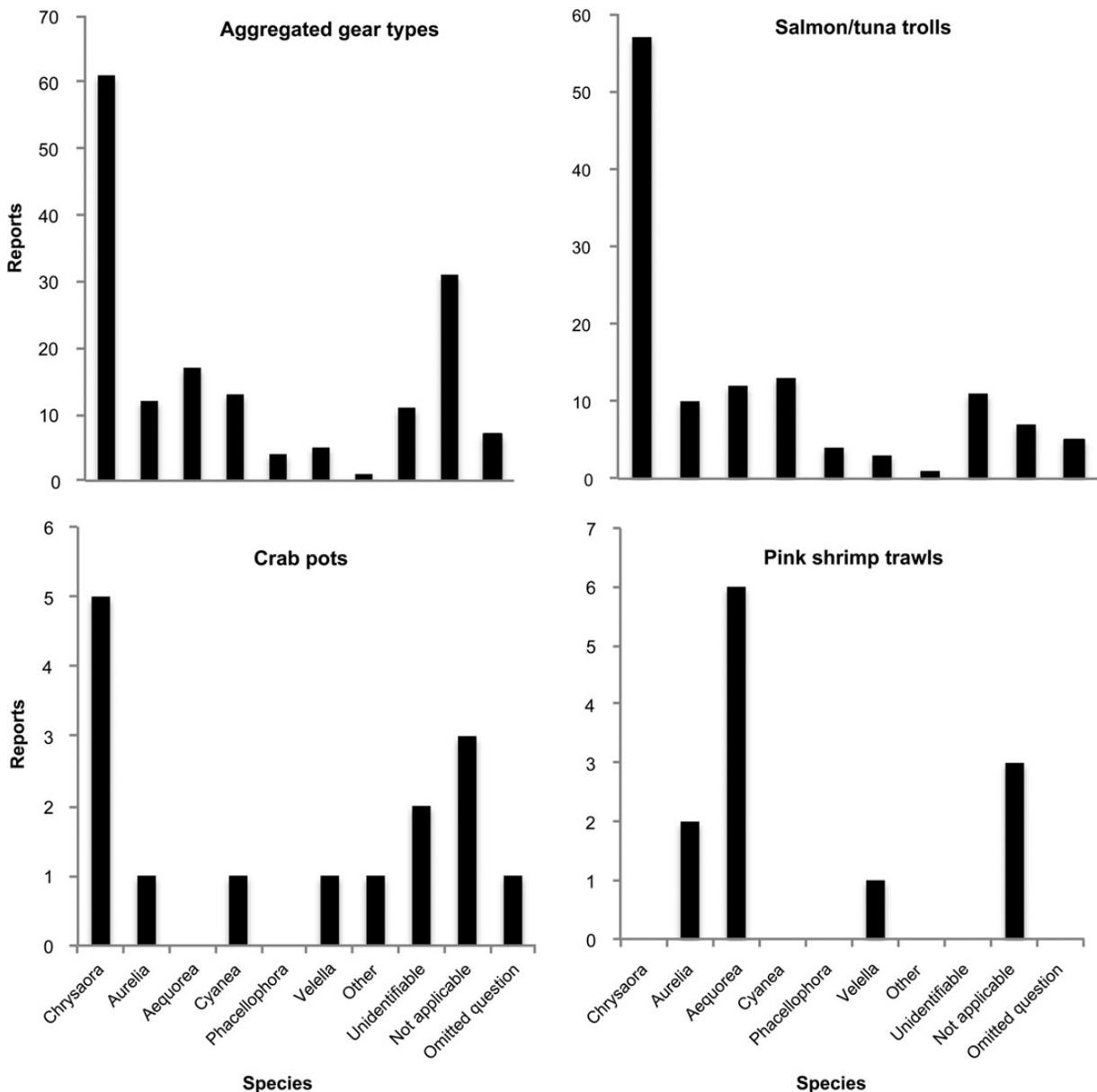


Figure 2. Scyphozoan jellyfish species reported to account for revenue losses for nuisance to different fishing gear types in the NCC, identified by respondents using colour photographs ($n = 81$). If a single respondent reported multiple species, each species was counted separately. "Other" constitutes a species reported as "acorn jelly", presumably the mesopelagic coronate jellyfish *Periphylla periphylla*. Scales differ based on differences in the number of respondents for different gear types.

reported never experiencing jellyfish stings during their fishing, or only being stung once every few months in peak jellyfish season (20%; Figure 3). Those infrequent stings were reportedly associated with only mild pain (Figure 4). Five fishers reported gloves serve as a simple, effective remedy for preventing stings. Although crabbers were not surveyed directly, some respondents commented on the impact of jellyfish on their crabbing activity because some respondents participated in more than one fishery. The one respondent who did report severe pain associated with jellyfish stings was a crabber. Two additional respondents reported mild pain, but noted severe pain when stung in their eyes while crabbing.

Oregon had 480 active salmon vessels in 2012, not counting tribal fishery vessels. Of those 480 vessels, 310 use troll gear and 167 use net gear. The salmon net fisheries are confined to the Columbia River, and the survey was restricted to commercial salmon trawlers fishing at sea. Multiplying the average revenue loss, calculated from the total estimates provided by respondents for the various

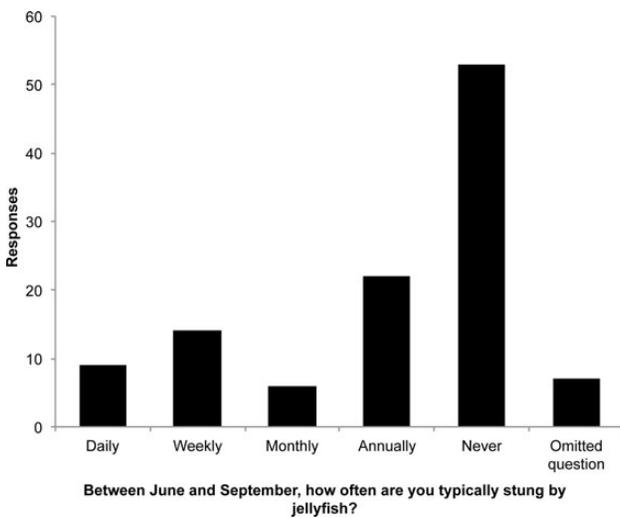


Figure 3. Respondents' assessment of frequency stung by jellyfish while fishing June–September ($n = 111$).

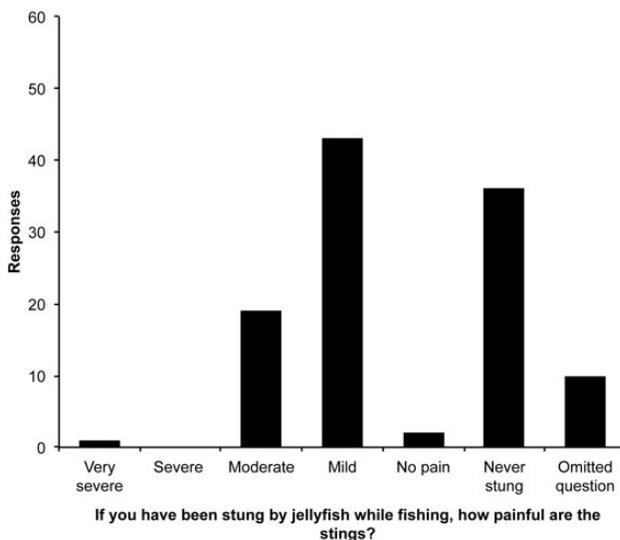


Figure 4. Respondents' assessment of pain caused by jellyfish stings ($n = 111$).

types of interference (Table 1; question 6; $n = 83$), by the number of active troll vessels, the economic impact of jellyfish on the Oregon salmon troll fishery is calculated to be roughly \$319 300 between June and September.

The Oregon pink shrimp fishery consisted of 64 active vessels in 2012. Multiplying the number of active vessels by the mean revenue loss calculated from estimates provided by respondents (Table 1; question 6; $n = 8$), the economic impact of jellyfish on the Oregon pink shrimp fishery is estimated to be \$334 200 between June and September. Evaluation of economic impacts was omitted for other fisheries because the response rate was too low ($\leq 10\%$ of the permit-holders) to extrapolate to the entire fishery.

Spatial patterns of jellyfish interference with commercial fishing activity

We asked about fishing locations on a mesoscale (hundreds of kilometres; Table 1; question 3) because fishers can be reticent to share their fine-scale fishing locations, but some respondents volunteered specific fishing locations that consistently experience problematic jellyfish abundance (Point Reyes Peninsula, Tillamook Head, Cape Lookout), as well as the locations that tend to be free of jellyfish (Table 1; question 13). Winchester Bay was the location with the highest median nuisance level, while Rogue Canyon and the Cape Blanco environs had the lowest nuisance level. Fishing activity in central Oregon was characterized by higher nuisance from jellyfish than fishing activity farther north or south (Figure 1b).

Comparison of total fishing effort by Project CROOS fishers to total weighted nuisance reported by survey respondents showed two regions associated with low aggregate fishing effort and low reported jellyfish nuisance; two regions with low effort, moderate nuisance; and two regions with high effort, high nuisance. Highest jellyfish nuisance corresponded to those regions with the most salmon trolling effort (Figure 5).

Fishers' perception of jellyfish population trends

Forty-six per cent of respondents were able to pinpoint a precise year(s) in which they observed the highest jellyfish abundance

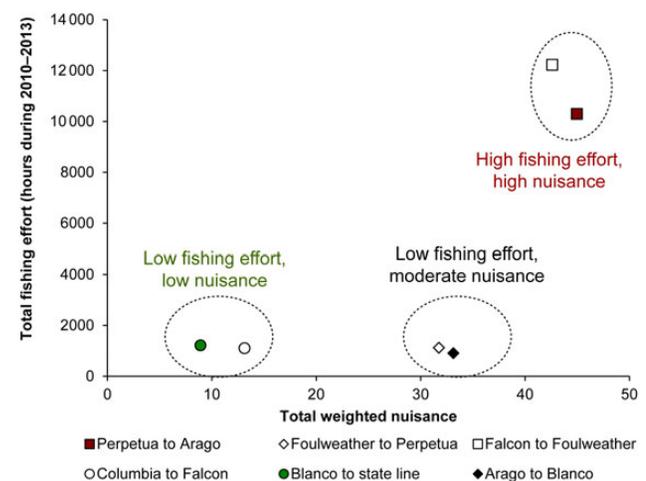


Figure 5. Comparison of total aggregate fishing effort (h) by the Collaborative Research on Oregon Ocean Salmon (Project CROOS) salmon fishers to total weighted nuisance reported by survey respondents in specified Oregon fishing regions.

(mode = 2011; $n = 53$; Figure 6). Seven respondents commented on the unpredictable nature of blooms and/or the high degree of interannual variability in abundance and, subsequently, nuisance. However, most fishers did not report a consistent change in jellyfish population trends in their respective fishing locations in the last 5 years (51%; Figure 7).

Discussion

Jellyfish reputedly impose nuisances on human activities, including commercial fisheries, but an examination of the nature of these impacts is often lacking. Our results demonstrate that jellyfish can have negative impacts on fishing operations even in fishing regions that are not considered to be severely disrupted. Our results show that jellyfish cause revenue losses to salmon trollers in the NCC. To our knowledge, this is the first study to elucidate jellyfish impacts on hook and line fisheries; all previous studies have found impacts only on net gears. This finding has implications for many other regions where this gear type is employed by fishers. Furthermore, we identified considerable agreement between fishers' perceptions and scientific information on jellyfish blooms, pointing to the value of semi-quantitative observations in furthering jellyfish ecology research.

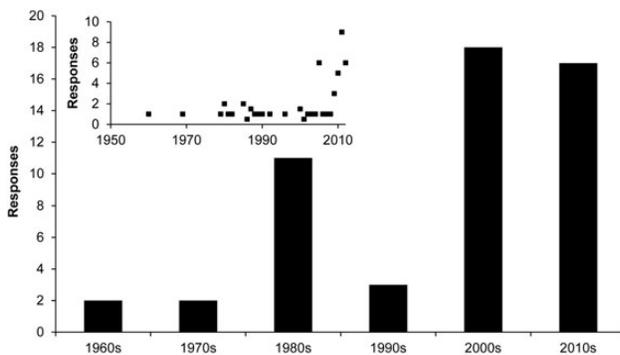


Figure 6. Respondents' report of year(s) with maximum jellyfish abundance pooled by decade ($n = 53$). Inset shows data without decadal bins ($n = 53$).

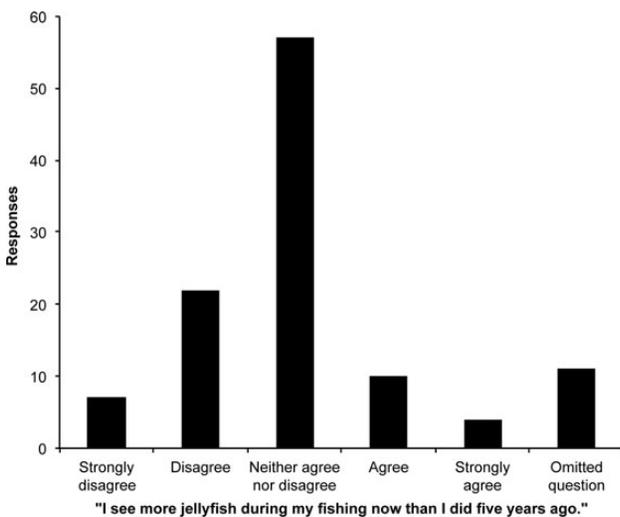


Figure 7. Responses to whether jellyfish have increased between 2007 and 2012 ($n = 111$).

Jellyfish interference with commercial fishing activity

Respondents' reports of high jellyfish nuisance in central Oregon were consistent with the known spatial distribution of *C. fuscescens*, the species reportedly accountable for most interference with fishing activity. Fishers' accounts of the highest gelatinous zooplankton biomass in shallow sites (principally *C. fuscescens*) were also consistent with scientific literature, and may be explained by the increased primary productivity in estuarine and neritic zones (e.g. Lilley *et al.*, 2011). Of course, perceptions cannot replace scientific monitoring, but the two can complement each other (e.g. Leleu *et al.*, 2012); fishers' perceptions could be used in combination with ecological monitoring of jellyfish to inform management strategies.

Our results represent the first report of jellyfish interference with trolling and longline gear; previous studies have found an impact only on set, trawl, and gillnets, and seines (Purcell *et al.*, 2007; Nagata *et al.*, 2009). Hook gear has previously been assumed to be impervious to jellyfish problems, but our study suggests jellyfish may affect a wider range of fishing gears. Although salmon trollers reported a lower mean revenue loss than pink shrimpers, the salmon fishery is a much lower volume, lower net-value fishery, in which many trollers fish part-time for supplemental income. Therefore, on an individual basis, the proportional revenue reduction may be comparable despite the seemingly disparate economic impact.

This study revealed that many fishers do not equate increased labour with increased costs. Fishers may report increased hours of labour removing jellyfish snared on hooks as merely a "nuisance", whereas reduced catch or fuel for relocating because of jellyfish are considered "revenue losses". In future studies, therefore, it may prove fruitful to ask about additional labour caused by jellyfish presence, and assign an hourly rate rather than directly inquiring about lost revenue. On the one hand, if a standardized economic value were assigned to labour, the costs associated with jellyfish blooms may be substantially higher than the values quantified here. On the other hand, the finding that fishers do not connect jellyfish-related labour to increased costs may be consistent with relatively stable populations of jellyfish through time; in other words, handling jellyfish, which are a component of the marine ecosystem, is simply part of the job.

Fishers did not perceive the pain caused by jellyfish stings to be a serious impediment to their work. This contrasts with the finding of a study in the southern Brazilian Bight, where the cubomedusae *Chiropsalmus quadrumamus* and *Tamoya haplonema* and the hydromedusa *Olindias sambaquiensis* caused painful stings, reportedly making work "extremely arduous" for artisanal shrimp trawlers (Nagata *et al.*, 2009). The dissimilarity may be explained by the particularly painful envenoming by some species (Haddad *et al.*, 2002). An additional explanation is that many respondents in our study reported that wearing gloves was an effective preventive. Fishers in the Brazilian Bight, in contrast, opt not to wear gloves because it is too hot to do so (R. Nagata, pers. comm.). The Pacific Coast of North America has a very mild climate and therefore gloves were reported to be a feasible preventive for many of our respondents. The one exception to this is commercial crabbing. In both the mailed questionnaire and in a dozen informal interviews with fishers on Fisherman's Wharf, San Francisco, CA, and the Charleston Marina, Charleston, OR, commercial crabbers were the only respondents who consistently reported that jellyfish increase the strenuousness of their work. Jellyfish tend to ensnare on crab pots, causing tentacles to be flung in fishers' eyes when the

pots are retrieved—an occupational hazard for this particular fishery (K. Conley, pers. obs.).

The predictability of jellyfish aggregations around physical promontories, including Point Reyes Peninsula, Tillamook Head, and Cape Lookout, suggests that physical factors may be partly responsible for the location and extent of patches of medusae. Cape Blanco—the most westerly headland in Oregon—was not reported to be a nuisance area for jellyfish, although *A. labiata* concentrations are known to occur directly south of this region (Suchman and Brodeur, 2005) and mass occurrences of *Aurelia* have caused nuisance to fishers in other parts of the world (e.g. Uye and Ueta, 2004; Baumann and Schernewski, 2012).

A previous study has identified regions of high spatial overlap between juvenile Chinook and juvenile coho salmon and *C. fuscescens* (Brodeur et al. 2008, Figure 2). Our results show that these areas of high overlap are also locations where fishers report incurring high jellyfish nuisance (Figure 1). Furthermore, the regions of highest jellyfish nuisance corresponded to regions with the most salmon trolling effort (Figure 5). Since jellyfish interference with fishing appears a localized occurrence, the identification of high- and low-nuisance regions is a prerequisite for policy development.

This study represents the first socio-economic survey in North America to quantify the economic impacts of jellyfish on fishing operations. One published report exists about the direct negative effects of jellyfish on the commercial shrimping industry in the Northern Gulf of Mexico in 2000; Graham et al. (2003) estimated an impact of \$10 million during a 2-month concentrated “super-swarm” of invasive *Phyllorhiza punctuata*. While that estimate was based on a transient event of an invasive species, ours represents a baseline of jellyfish reduction in fishers' revenues across multiple fisheries. Using the mean revenue losses provided by respondents, the combined economic impact of jellyfish on Oregon's troll salmon and pink shrimp fishers can be roughly calculated at over \$650 000 in peak jellyfish season (June–September) in 2012.

This estimate assumes that the average cost reported by survey respondents reflects the entire sampling population, and that those fishers who responded to the survey do not differ substantially from those who did not. Although we could not directly analyse the bias of non-response, we believe this is a reasonable assumption because of the relatively large proportion of respondents who replied to the survey despite reportedly perceiving either no nuisance from jellyfish (19%) and/or reportedly incurring no economic cost (38%). Those fishers who reported incurring no economic cost (i.e. those who reported \$0 in impact in question 5, Table 1) were included in the calculation of average reduction in fishers' revenues due to jellyfish. Perhaps our survey results are subject to “interest bias”, a common form of non-response bias for mailed surveys whereby people who are more interested in the subject of the questionnaire respond more readily (e.g. Armstrong and Overton, 1977). However, the survey results do not suggest that such a bias influenced respondents' perceptions of nuisance or estimates of cost.

An additional limitation of the survey is that our estimates of economic impact may not adequately capture the labour costs associated with keeping gear clean of jellyfish. Many fishers reported that keeping gear clean in the presence of jellyfish blooms caused their work to be more laborious and time-consuming, but did not assign this an economic value. Perhaps jellyfish simply increase the arduousness of labour without this imposing a revenue loss. Alternatively, this cleaning process may reduce fishing productivity

and/or income by reducing the amount of fishing time as fishing gear is pulled in to be cleaned and then reset. These costs are difficult to quantify and may or may not be adequately captured by our survey estimates.

Fishers' perception of jellyfish population trends

Respondents' recall of year(s) with maximum jellyfish abundance (Figure 6) suggests a decadal-scale variability similar to the pattern described by Condon et al. (2013), which indicated two periods of increased likelihood of encountering jellyfish blooms: 1971–1985 and 1993–2004. Social science research has established, however, that recall is not always reliable and depends on time passed and the nature of the queried material (e.g. Bradburn et al., 1987); there may, therefore, be bias in retrospective data such as this. Furthermore, not all fishers have been fishing for the same amount of time, and some may not possess the experience necessary to recall multi-decade population fluctuations. On the shorter time-scale of 5 years, fishers' perceptions were that jellyfish populations have not changed (Figure 4).

Conclusions

Since jellyfish abundance may be indicative of ecosystem shifts (Suchman et al., 2012; Francis et al., 2012), establishing a “standard” socio-economic impact across different fisheries serves as a valuable reference point. It has been suggested that the expansion of hypoxia along the Oregon shelf may favour jellyfish over fish (Brodeur et al., 2008), but according to our results, fishers have not seen this materialize, and instead suggest stable populations.

Though not a substitute for rigorous scientific examination, this study documents the value of fishers as collaborators in scientific research, particularly for documenting population trends. Fishers' LEK may prove especially useful for poorly studied organisms such as scyphozoans, for which long-term time-series of abundance are often lacking. Fishers' perceptions can serve as a useful indicator of community changes. As one fisher said, “I have observed for a long time”. Although these data are semi-quantitative, they represent the first step towards understanding the scope of jellyfish impacts on fisheries in this region. Our intent is that this foundation will prompt more in-depth, quantitative analyses of economic impacts.

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