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Harvesters' perspectives on the management of British Columbia's giant red sea cucumber fishery

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ABSTRACT

In recent decades, sea cucumber fisheries have rapidly expanded worldwide to meet rising demand in Asian markets. Catch trends have often followed a boom-and-bust trajectory and skyrocketing sea cucumber value has often spurred fishery development that outpaced adequate biological research for informed stock assessment. Currently, the dive fishery for Giant red sea cucumber (*Parastichopus californicus*) in British Columbia, Canada is considered moderately exploited. However, basic population parameters such as recruitment and mortality rates are still largely unknown, creating important sources of uncertainty in the fishery's stock assessment model. This study presents the results of an interview-based survey of experienced commercial harvesters' (1) perceptions of local trends in sea cucumber abundance, size, and fishing effort (CPUE), and (2) perceptions of management efficacy. The majority of harvesters perceived abundance (14/20) and CPUE (15/20) to have declined over their careers, and half of the harvesters reported decreased sea cucumber size. The harvesters most commonly cited overfishing as the most pressing problem facing the fishery (13/20), and the majority felt that Fisheries and Oceans Canada (DFO) needed to lower licence and/or area quotas to avoid further declines. Despite many knowledge gaps in the fishery, almost all harvesters (16/20) perceived that they are not adequately consulted and their concerns are not adequately considered by DFO. These results suggest a disjoint between DFO forecasts and perceived local sea cucumber trends, and highlight that the fishery may lack a resource-rights framework with adequate checks to decouple fishing pressure from increasing global market value and demand. Maintaining the long-term health of the BC sea cucumber fishery may depend on working more closely with harvesters to inform future management decisions and, ideally, moving towards a harvester-owned-and-operated licencing system that can better integrate the feedback that comes from attachment to place.

1. Introduction

Over the past century, the global decline of finfish fisheries, an increasing need for new resources to harvest, and strong global market forces have led to a substantial expansion of existing and new invertebrate fisheries [1,2]. Global sea cucumber fisheries, in particular, have rapidly expanded in catch and value over the past two to three decades, with global catch and production (including aquaculture) increasing 13- and 16-fold to meet rising demand in Asian markets [3]. The bulk of the catch is exported to China, where both the reconstituted dried, salted flesh (termed bêche-de-mer or trepang) and muscle strips are consumed [4]. Stronger fishing pressure has often left a trail of serial exploitation in the form of species expansion, size depletion, and spatial expansion; consequently, since 1950, sea cucumber fisheries have developed increasingly far from their main market in Hong Kong [3].

One of the commercial sea cucumber fisheries to develop is the Giant red sea cucumber (*Parastichopus californicus*) dive fishery in British Columbia (BC), Canada. Beginning in 1971, the fishery initially followed the typical trajectory of a boom-and-bust pattern but management measures implemented in the 1990s allowed stocks to recover [3,5]. Currently, BC's sea cucumber fishery is considered 'Moderately exploited' – meaning the exploitation rate is considered to leave some potential for further expansion without decreasing the reproductive capacity of the stock [6].

The BC sea cucumber fishery is managed using a total allowable catch (TAC; currently 1.36 million lb), limited entry licencing (85 licences each assigned 16,000 lb of the TAC), area licencing, and area quotas [7]. Licence area quotas are divided into management units termed Quota Management Areas (QMAs), and QMAs are further divided into subareas. QMA quotas are set using subarea biomass estimates calculated from density transect surveys [7].

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When there are survey data, the lower 90% confidence bound of the density is used; otherwise, predefined baseline densities are used [7]. DFO collaborates closely with the Pacific Sea Cucumber Harvesters Association (PSCHA), which aims to represent the interests of licence holders with regards to marketing and fishery management, to undertake surveys and monitor the stock [7]. Final changes to the season's management plan may be made after the annual Sea Cucumber Sectoral Committee (SCSC) meeting, which provides representatives of the Pacific Sea Cucumber Harvesters Association and industry stakeholders a forum to advise on stock assessment, biological research, the management plan, and long-term management strategies for the species [7].

Fisheries and Oceans Canada (DFO) aims to conserve sea cucumber stocks by applying risk-averse management based on the best available science [7]; however, there are several acknowledged biological challenges to sustainable management of sea cucumbers, including *P. californicus*. First, rates of recruitment, growth, natural mortality, and immigration/emigration are still unknown for this species [8]. Second, sea cucumbers are broadcast spawners and the minimum population density needed to ensure *P. californicus* reproduction and population growth is still unknown [9]. Third, *P. californicus* larvae are planktotrophic and may disperse large distances from fished areas before beginning their benthic stage 65–125 days later [10] – a life-history trait that when coupled with broadcast spawning can slow recovery in an area if overfishing has reduced population size [11]. A long potential lifespan may further contribute to population density variations, particularly if recruitment is low [11]. The consequence of this biological uncertainty and variability is that several assumptions of the productivity model used to set harvest rates may be violated, particularly those concerning rates of biomass recovery, factors external to fished areas that affect vital rates and recruitment, and the lag time between reproduction and recruitment [8].

In the early 2000s, BC sea cucumber harvesters identified that the annual fishery implemented in 1997 was causing size depletion – often an early warning sign of resource depletion [3] – and requested a return to a rotational harvest [8]. Analysis of data collected during the annual fishery confirmed that annual harvest rates were being exceeded on local scales due to effort concentration [12]. In response to these concerns, DFO implemented a three-year rotational harvest strategy in 2011 to allow managers to control the frequency of harvest through spatial rotation [12]. Under this strategy, DFO assigns a harvest rate of up to 10% of predicted biomass to each QMA once every three years, with the exception of those in the West Coast of Vancouver Island licence area, where there is not enough biomass to support a rotational-style fishery [7]. To enable the rotational harvest, DFO expanded the coastline available to the fishery from 25% to 47% in 2012 [7]. Given that the rate of recovery after harvest remains a critical point of uncertainty in the stock assessment model, this rotational strategy will require continued monitoring and adaptation to changes in the resource.

A means of providing a fishery with greater capacity to adapt to changes in the resource – and a key step to maintain resilient social-ecological systems – is to increase harvester participation in management and incorporate local ecological knowledge (LEK) into management plans [13,14]. Using social–ecological surveys to document LEK can complement stock assessments and scientific surveys and help address conservation issues [15–18]. In this study, the three central objectives were to (1) survey commercial harvesters' perceptions about local trends in sea cucumber abundance, size, and fishing effort, and management efficacy in the BC sea cucumber fishery, (2) gather harvester knowledge of sea cucumber biology, and (3) summarise harvesters' recommendations about how to improve the sustainability of the fishery. To the author's knowledge, this study represents the first harvester-relayed assessment of this fishery.

2. Methods

From July to October 2013, 20 sea cucumber harvesters were interviewed. Study participants were recruited using snowball sampling, a sampling technique where existing respondents recruit future respondents from within their community [19]. In this study, colleagues and D&D Pacific Fisheries Ltd. – the service provider contracted by the Pacific Sea Cucumber Harvesters Association to provide notification, validation, and biological sampling services for the fishery – recommended harvesters with long-term experience in the fishery. These harvesters in turn recommended other harvesters with long-term (approximately greater than 10 years) experience in the fishery. This targeting of 'expert' harvesters limited the ability to measure variability and bias [19], but enabled interviewing those who have greatest insight into how the fisheries' dynamics have changed over time [20]. Due to constraints on some respondents' time, 11 harvesters were asked an abridged version of the questions. Therefore, sample sizes vary by survey question. Informed consent was obtained verbally.

Interviews were semi-structured, allowing respondents to relay anecdotes and dictate the scope and direction of the interview. Full-length interviews averaged 64 min in duration (range 30–110 min) and abridged interviews were <20 min. Respondents were first asked to provide general demographic information, such as age, household size, and ethnic origin. The second set of questions collected baseline information for calibrating responses by asking harvesters to detail, for example, when they entered the fishery, and the licence areas where they typically dive. The body of the interview was comprised of questions on harvesting-specific issues and perceived efficacy of management. For example, respondents were asked how the abundance of sea cucumber has changed, if at all, since they began working in the fishery. Responses related to change in abundance and catch per unit effort (CPUE) were reported on a 5-point Likert-like scale (e.g., has abundance 1=declined dramatically, 2=declined somewhat, 3=stayed the same, 4=increased somewhat, 5=increased dramatically). Many respondents also stated they harvested geoduck (*Panopea generosa*) and/or red sea urchins (*Strongylocentrotus fransiscanus*). Observations offered by these respondents about trends or management issues in these fisheries were noted and are summarised in Appendices A and B. Respondent answers were transcribed during the interview but not audio recorded.

3. Results

3.1. Harvester demographics

The mean age of sea cucumber harvesters interviewed in the full-length interviews was 48 years (range 41–55 years). Seven of 12 respondents had their permanent residences on Vancouver Island, three on the Central Coast, one on the North Coast, and one in Vancouver. 12 of all 20 respondents were Canadians of European descent, four were European, four were Aboriginal (First Nations, Métis).

The 20 respondents had fished sea cucumbers commercially for a mean of 20 years (range 8–35 years), and spent a mean of 29 days (range 14–38) per season diving for sea cucumbers. 19 of 20 respondents reported that they harvested sea cucumbers on the Central Coast. This number includes all 'expert' harvesters on 11 of 14 vessels that had a licence to fish the Central Coast in 2013. Nine

of 20 harvested on the North Coast, three on the East Coast of Vancouver Island, and four on the West Coast of Vancouver Island. Nine of all 20 respondents owned their own vessel and only three were licence holders. Respondents fished a mean of four licences each season (range 1–9, $n=20$).

3.2. Fishery trends

3.2.1. Abundance

When asked how the abundance of sea cucumbers has changed since they began working in the fishery, 14 of 20 respondents felt that abundance had declined either somewhat or dramatically, depending on the area (Fig. 1). Six respondents felt that abundance had remained the same; though of these respondents, five noted that areas where very large sea cucumbers had been harvested never recovered.

Of the 14 respondents who felt abundance had declined, all reported overfishing as the main reason for the decline in abundance. These respondents attributed overfishing to licence quotas being set too high (50%), the annual harvest not having allowed sufficient recovery time (21%), and overestimates of QMA biomass (28%). Two of these 14 respondents felt that declines had stabilized or that sea cucumbers were increasing in abundance again since the rotational harvest was implemented. Areas that respondents commented had low abundance versus high abundance are listed in Appendix C.

Fig. 1. Frequency of harvester responses to questions regarding key fishery trends and management issues. Responses given were (from top to bottom): (1) abundance: over my career, sea cucumber abundance has declined (either somewhat or dramatically, depending on the area), or no change; (2) CPUE: it declined (either somewhat or dramatically, depending on the area) over my career, or no change; (3) size: sea cucumber size has declined (either somewhat or dramatically, depending on the area) over my career, or it declined during the annual harvest but is recovering since the implementation of the rotational harvest, or no change; (4) top challenges: when asked what they thought were the three top problems/challenges in the fishery, harvesters cited overfishing, the owner–operator system, high lease price, work safety violations, or no major issues; (5) licence holder interests: not consistent with the interests of harvesters, or consistent with the interests of harvesters, or no answer; (6) harvester consultation: harvesters are not adequately consulted in the management process, or harvesters are adequately consulted; and (7) harvester wages: my wage has declined over the course of my career, or no change, or my wage has increased. The number of responses compared to the number of respondents is indicated on the right.

3.2.2. Effort

Of all 20 respondents, 15 reported that their CPUE had declined either somewhat or dramatically, depending on the area (Fig. 1). Respondents reported declining abundance and size of sea cucumbers as the main reason (14/15) why they had to work harder to fill quotas. 13 of 20 respondents reported having to dive longer, and 15 reported diving deeper (to a range of 50–80 ft; most of these 15 harvesters tried to stay above 35 ft, but dove up to 50 ft now). Respondents that were not diving deeper (remaining at <35 ft) cited safety concerns (e.g. decompression sickness) and preferring to maximise bottom time as reasons for this decision. Of the 15 respondents who felt CPUE had declined, one felt that it was increasing again since the rotational harvest was implemented. Only five of 20 respondents felt that CPUE had not declined and that they were not diving deeper or longer. Respondents who reported no change in their CPUE stated that improved harvesting efficiency and continuing to find areas with abundant sea cucumbers were the main reasons for the lack of change.

3.2.3. Sea cucumber size

When asked if they could provide the mean length of sea cucumbers harvested in 2012, respondents could only provide rough estimates as size varied from area to area. The mean size reported by respondents was 12 in., though respondents mentioned sizes could be as small as 6 in. and as large as 2 ft. Five of 20 respondents noted that areas with higher recruitment rates were generally those with smaller sea cucumbers (e.g. Grenville Channel, Johnstone's Strait), whereas areas with large individuals had low recruitment rates or did not recover after harvest (e.g. Cougar Bay, West side of Banks Island). Half of the 20 respondents felt that the size of cucumbers had declined over the course of their career (Fig. 1). An additional five respondents felt that size had declined during the annual harvest but that the rotational fishery was allowing sea cucumbers to increase in size again. The remaining five felt there had not been any decline in size.

3.3. Management

3.3.1. Top challenges or problems

When asked in an open-ended question to identify what they considered to be the top three challenges or problems currently facing the sea cucumber fishery, most respondents identified overfishing (13/20) and the owner–operator system (12/20) (Table 1, Fig. 1). Prohibitive lease price (4/20) was the next most cited problem, followed by work safety violations (1/20). Only four respondents identified that there were no major issues. Of four respondents who reported sitting on the Pacific Sea Cucumber Harvesters Association management board and/or Sea Cucumber Sectoral Committee, none identified overfishing as a problem. All respondents who were neither on a management board, nor currently a diver on a vessel operated by a board member, identified overfishing to be a problem.

3.3.2. Licence holder vs. harvester priorities

When asked whether they feel licence holders and harvesters share the same priorities or interests in the fishery, 17 of 19 respondents responded 'No', one responded 'Yes', and one provided no answer (Fig. 1). Six respondents elaborated that licence

Table 1
Components of each issue reported by sea cucumber harvesters when they were asked "What do you think are the three most pressing problems/challenges in the sea cucumber fishery?" Responses were not constrained to these categories but grouped into these issues once all interviews were completed.

Issue	Components of the issue
Overfishing	• Licence and QMA quotas are too high • In response to size depletion and abundance declines, DFO has allowed the spatial expansion of the fishery • Scientific assessments are not accurately reflecting the health of the fishery • Areas have not been left unharvested long enough for populations to recover • The rotational harvest alone is not a solution to overfishing if the quotas are not also decreased
Owner–operator system	• Most licence holders (many of them buyers and processors) do not fish their licence but lease it to harvesters, therefore protecting their assets (i.e. maintaining high lease prices) does not require sustainably-managed stocks • DFO consults only with licence holders and very few divers are licence holders, therefore those keen to preserve the resource and possessing on-the-ground knowledge of the stocks are not represented in the management process • Licence holders should be mandated by DFO to fish their own licences; or at minimum, there should be a cap on the number of licences that buyers and processors can own
Lease price	• Lease prices are too high • Prices are so high that fishery profits stay with licence holders and not with the harvesters • Almost no bargaining on lease prices
Work safety	• DFO should regulate to whom licence holders can lease their licences to • Licence owners are aware that some harvesters are not following work-safety regulations (e.g. diving alone, diving deep enough to get decompression sickness), but lease to them regardless

holders were interested in keeping quotas high to maintain high licence lease prices, whereas harvesters were interested in earning a living from the fishery but not at the expense of its long-term sustainability. These respondents felt harvesters, not licence holders, had to bear the financial costs associated with declining CPUE. The respondent who responded 'Yes' felt that licence holders also want a sustainable fishery, and pay fees to DFO that go towards sea cucumber surveys and research. However, a different respondent noted that it is ultimately harvesters who pay these fees as that cost is subsumed in the lease price.

3.3.3. Switch to rotational harvest strategy

Over half of harvesters (13/20) felt that replacing the annual harvest strategy with a three-year rotational harvest strategy was a 'good' management change because the annual harvest did not allow enough time for sea cucumbers to recover. Two felt that it was a 'bad' change, because it was coupled with unsustainable increases in area quotas to maintain the TAC. Two other respondents felt that the rotational fishery would make no difference to stock health unless the licence quotas were also decreased. The remaining three respondents felt they could not say whether it was a 'good', 'neutral', or 'bad' change until they observed the results of one to two cycles. When asked whether they felt that the length of the harvest cycle was appropriate, the majority of respondents (12/20) felt that the fishery would need to determine this with monitoring over time. Four felt that a three-year cycle was appropriate. Three felt the fishery should consider different cycle lengths for different areas, given area-specific growth and recruitment rates.

3.3.4. Harvester consultation

Most respondents (16/20) felt that harvesters are not adequately consulted and involved in sea cucumber management (Fig. 1). Of these 16 respondents, three elaborated that because licence holders are a strong lobbying force for higher quotas, divers fear losing their jobs if they share concerns about overfishing. Additional reasons mentioned for lack of harvester attendance at management meetings included that harvesters are often working when meetings are held. 12 of these 16 respondents (75%) also felt input from harvesters had generally not been effectively incorporated in DFO's management plans. Two of 20 felt that harvesters were adequately consulted but that divers did not adequately partake in the management process. Another two felt that harvesters were adequately consulted and involved.

3.3.5. Profit distribution

As of 2012, sea cucumber market value has increased from a mean of ~$1.54 per split pound in 1993 (the mean year respondents entered the fishery) to a mean of $5.25 per split pound [7]. However, of 10 respondents, almost all reported that harvester wages have remained the same (6/10) or decreased (3/10) since they began working in the fishery (Fig. 1). Respondents cited two reasons for this trend: first, that they had to pay higher licence lease prices though wages have not increased (4/9), and second, that they were working longer and harder for the same catch as abundance and sea cucumber size has declined (1/9). Four of 10 respondents perceived that only licence holders have been making more as the sea cucumber market value and licence lease prices have increased (respondents reported the current cost to lease a licence was $70,000–78,000). Only one of the respondents, a licence holder, reported an increase in wage. Respondents ($n=5$) who dive for sea cucumbers but do not own licences or a vessel, reported earning $\$6733 \pm 1104$ ($\bar{x} \pm \mathrm{SE}$) per licence on average (before tax deductions). Six of nine respondents thought that the move from an annual to rotational harvest strategy would make the fishery less profitable for harvesters because of the greater expenses associated with travelling further between QMAs.

3.4. Recommended management changes

When asked in an open-ended question whether there were management measures they thought needed to be taken, the majority of respondents (12/20) reported that they would lower the licence quota (Table 2). Eight of these 12 stated it should be lowered by a mean of 4688 ± 801 lb ($\bar{x} \pm \mathrm{SE}$; range 1000–8000 lb). More than half of respondents (11/20) stated they wanted to see more basic research, including more accurate density surveys that accounted for locations in the QMAs that produced few or no sea cucumbers, continued monitoring of the efficacy of the rotational harvest strategy, and increased research on *P. californicus* biology.

Table 2
Management measures that harvesters ($n=20$) stated they would implement when asked "Are there management measures you think need to be taken to better manage the sea cucumber commercial fishery?" and the frequency of their mention.

Management measure	Frequency
Lower licence quota	12
More sea cucumber biology research, density surveys, and monitoring	11
Greater size selectivity	2
Lower area quotas along with opening more coastline for harvest each season	2
Open the Haida Gwaii for harvest	2
Make mandatory that licence owners be harvesters	2
Make QMAs smaller	2
Close more areas to the fishery	1
Keep vessel licence stacking limit	1
Greater enforcement against poaching by aquaculture	1
VMS on all vessels to monitor work safety and greater penalties for violations	1
Raise licence quota	1
None	1

3.5. Knowledge gaps

3.5.1. Immigration and recovery

When asked whether they thought sea cucumber recovery is driven by immigration of adults or settlement of larvae/recruitment of juveniles, most respondents (13/19) felt that both must play a role, but to unknown degrees. Four thought that immigrating adults must be the primary drivers of recovery – either because they believed juveniles could not have grown enough over the closed months during the annual fishery or because they rarely see juveniles. The remaining two respondents could not say to what degree immigration or recruitment plays a role.

When asked whether adults migrate primarily vertically or horizontally, nine of 19 respondents stated adults primarily migrate from deep to shallow water. Nine stated that they must migrate in both dimensions. The remaining respondent could not say. Five respondents mentioned they did not feel there were inexhaustible numbers of adults in deep water or that in some areas they had not seen adults replace what had been harvested.

3.5.2. Juvenile biology

Most respondents (12/18) had few observations of juveniles. Some respondents (6/18) noted that juveniles seem to be often found around clam, scallop, oyster, and geoduck beds, which may provide shelter. Others (3/18) felt larvae likely settle in many places, depending on currents, tides, and storms.

3.5.3. Resurveying

All respondents asked ($n=14$) had participated in sea cucumber dive surveys. Areas mentioned by divers that they would prioritise for resurveying the abundance of sea cucumbers included Laredo Channel, Sheep Channel, Griffin Passage, Mathieson Channel, and the Gulf Islands. Some respondents felt that the West Coast of Vancouver Island in general had been largely unexplored.

4. Discussion

Increasing demand for marine resources and globalisation of resource markets has driven a global expansion of invertebrate fisheries that has outpaced the ability of scientists and managers to adequately assess stock status and ecosystem impacts [1]. This pattern has not been unique to developing nations [21,22]. Managing BC's commercial sea cucumber (*P. californicus*) fishery, DFO states its first priority is the conservation of marine resources [7]; however, accurate long-term forecasts of *P. californicus* stock status are challenging because vital population rates are still unknown [12]. In this study, 20 experienced BC sea cucumber harvesters were interviewed to survey their perceptions about local sea cucumber population trends, biology, and fishery management efficacy. Almost all harvesters perceived abundance, CPUE, and sea cucumber size to have declined over the course of their careers, which they attributed to quotas being set too high and insufficient recovery time. Most felt that implementing the rotational harvest was a beneficial and necessary strategy that would help prevent overfishing; however, most also felt that if DFO does not lower licence quotas, declines in abundance, CPUE, and sea cucumber size may continue. Most harvesters would also like to see more research into *P. californicus* biology, as well as more density surveys. Harvesters are knowledgeable and invested in the fishery, but perceived that they are not adequately consulted and that their concerns about overexploitation have not been adequately considered by DFO. These results highlight that BC's sea cucumber fishery may be taking on too much risk given current levels of uncertainty about local population health.

Most local harvesters felt that overfishing is the most important problem with BC's sea cucumber fishery. They identified three key misassumptions about local sea cucumber populations as having contributed to the disjoint between DFO forecasts and on-the-ground outcomes. First, many harvesters emphasised that not all sea cucumbers are equal. They reported observing differences in productivity, recruitment rate, and sea cucumber size within and across areas. Consequently, recovery rates can be different between sea cucumber patches. For example, six of 20 harvesters stated that areas with large sea cucumbers often do not recover as rapidly or at all, which can lead to local extinctions. In calculating stock productivity, DFO accounts for differences in biomass between subareas when setting quotas by taking fishery-dependent or -independent weights of individual sea cucumbers. However, DFO does not account for differences in productivity that follow from differences in size or population-specific recovery rates. Second, many harvesters identified that fishery catch trends can mask local declines in abundance. Most divers tried to stay above 35 ft, but 15 of 20 reported that they now dive down to 50 ft or deeper (maximum reported depth of 80 ft), which was not necessary when they began their careers. Some divers expressed concern that they are removing individuals that would have migrated upwards to replace those harvested at shallower depths. Such spatial expansion can mask regional depletion, a common characteristic of serial exploitation [23,24]. Third, the majority of harvesters felt that density transect surveys are not adequately capturing spatial variation in density. They stated that measured densities are frequently applied on too broad a spatial scale and that many locations do not have the abundance of individuals to support the quotas DFO sets. As a result, some harvesters sometimes find themselves removing more individuals in a location than they feel will allow recovery in sufficient time. Some harvesters questioned whether the switch from an annual to rotational harvest came too late in heavily depleted areas to reverse declines in abundance.

Even given the rotational harvest, sustainable fishing levels are uncertain because the minimum population density for successful spawning and the rate of population recovery are unknown. DFO must make assumptions about these biological parameters because they lack the necessary data. Indeed, the DFO acknowledges "for reference points to be useful, [sea cucumber] stocks must be monitored on a regular basis in order to see whether changes are occurring…and the department does not have the money or personnel to monitor all commercially harvested areas in BC on a regular basis" [7]. Recent dismantling of environmental

legislation and funding cuts to DFO and other government environmental departments will further challenge the capacity of DFO to conduct basic research and monitoring, as well as infringe upon DFO's stated aim to adopt ecosystem-based resource management [25,26]. Harvesters may therefore be an even more essential resource for information on local population trends. Yet, the overriding sentiment amongst the harvesters interviewed was that they have little input into the management process. Harvesters cited two main reasons for this sentiment: (1) the Pacific Sea Cucumber Harvesters Association primarily represents the interests of licence holders, of which few are harvesters, and (2) licence holder priorities often conflict with those of harvesters.

In BC, commercial sea cucumber licences can be (and most are) held by merchants and processing companies, and these companies may make substantial short-term profits from leasing their licences to harvesters at a high cost. High quotas help to maintain a high lease price. One respondent mentioned that harvesters tried many years ago to create a divers' association so that they would have a voice distinct from that of licence holders, but that threats from some licence holders ended this effort. Harvesters are also not represented on the Sea Cucumber Sectoral Committee. Sea Cucumber Sectoral Committee advisors are selected from four groups: Aboriginal, Commercial Licence Holders, Processors, and Other Representatives (e.g. D&D Pacific Fisheries Ltd., provincial government, aquaculture, non-commercial users) [27]. Commercial Licence Holder representatives are either licence holders of record voted in by DFO, or representatives chosen by the Pacific Sea Cucumber Harvesters Association licence holders. This may help explain why harvesters who reported being active on Pacific Sea Cucumber Harvesters Association and/or Sea Cucumber Sectoral Committee management boards share a view of the fishery that is in opposition to that of the majority of harvesters. For harvesters who have been able to attend meetings, some expressed the concern that they have little influence with DFO. For example, one respondent, speaking as a licence holder as well as an active harvester, reported having voiced concerns about overfishing to DFO during the Sea Cucumber Sectoral Committee meeting on two different occasions and being told on both occasions that they would not be able to consider his feedback at that time. Whatever the reasons, many harvesters mistrust the management process, feel they have little incentive to participate, and/or fear reprisals from licence holders for being too vocal about their concerns.

Addressing the ecological effects of globalisation and 'roving banditry' requires that local authorities have a resource rights framework in place that aligns individual self-interest with the long-term health of the resource [24]. BC's sea cucumber fishery does not have such a resource rights framework. As designed, the limited-entry licencing system does not require that those who own the rights to the resource be local harvesters. Additionally, it assigns greater weight to licence holder interests, which 17 of 20 respondents felt were not consistent with maintaining the resource for commercial use in perpetuity. A check to dampen the fishery's rate of expansion under increasing global demand would be to mandate that licences be issuable and transferable only to active harvesters. This would be beneficial for two key reasons. First, it would help to develop the conservative feedback that comes from attachment to place [24]. Indeed, as evidenced by the recommendation most cited by harvesters – lower licence quotas – harvesters support more conservative fishery management. Going forward, harvesters would also like to see the uncertainty around several biological unknowns reduced (e.g. identifying areas where larvae settle, determining area-specific juvenile growth and recruitment rates, assessing recovery rates, and identifying whether there are genetic factors that influence area-specific size differences). Second, mandating that licences be issuable and transferable only to active harvesters would encourage lower licence prices and ensure that profits remain with harvesters. As part of such a resource rights framework, greater transparency about licence statistics, fishery participation, and earnings is also needed to keep interested parties apprised of changes in resource access. As an example, this information is publicly available online for limited and unlimited fisheries in Alaska through the Commercial Fisheries Entry Commission [28], but this is not the case in BC.

DFO states that "there is no indication of concern for sea cucumber stocks at this time" [7]. In contrast, the majority of harvesters interviewed in this study did not share this view. This discrepancy in perspectives is either evidence that the fishery's stock assessment model poorly captures local population trends, or, at a minimum, it is evidence of a lack of communication between DFO and harvesters. If BC hopes to avoid the boom-and-bust trajectory that has been so typical of global sea cucumber fisheries [3], it will require concerted effort to work with harvesters to resolve potential issues and to put checks in place to ensure that cautious voices are heard by fisheries management.

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Appendix A. Harvester perspectives on the BC geoduck fishery

Harvester demographics

The mean age of geoduck harvesters interviewed was 51 (range 47–55, $n=3$). All respondents were of European descent ($n=6$). Respondents had been fishing geoduck commercially for a mean of 21 years (range 17–26, $n=3$).

Fishery trends

Abundance

When asked how the abundance of geoduck has changed since they began working in the fishery, five of five respondents felt that abundance had declined somewhat, and dramatically wherever sea otters were present. Respondents cited predation of geoduck by sea otters (5/5) and licence quotas being too high (4/5) as the two reasons for the decline in abundance.

Effort

Of five respondents, four reported that their CPUE had declined somewhat (80%, $n=5$), and one reported CPUE had declined dramatically (20%) where sea otters have expanded.

Management issues

Sustainability

When asked in an open-ended question to identify what they considered to be the top three problems or challenges currently facing the geoduck fishery, all (6/6) respondents identified sea otter predation. Respondents stated sea otters had "devastated" areas they had expanded into, compounding the next most cited challenges: (1) overfishing (3/6) and the owner–operator system (3/6) – as with the sea cucumber fishery, most licences fished by harvesters are owned by non-harvesters; respondents felt the quota would not be so high if licences had to be owned by harvesters. Respondents' recommendations included lowering the licence quota by 10–15% to ~51,000–54,000 lb s per licence and increasing the length of the rotational harvest cycle from 3 years to 6 years; (2) maintaining high product quality and market value (3/6) – for example, respondents noted that competition with Alaskan, Washington, and Mexican markets negatively affect market prices for BC geoduck, and that high-grading by BC harvesters was a problem. To monitor harvester behaviour, one respondent recommended that VMS and cameras be mandated on all vessels. Sea otter predation was said to further compromise the quality of geoduck meat by forcing geoducks to spend less time with siphons exposed.

Aquaculture

Three of three respondents felt that geoduck aquaculture should be expanded. One third of these respondents felt that it should be developed on land out of concern for potential negative impacts on wild stocks.

Appendix B. Harvester perspectives on the BC red urchin fishery

Harvester demographics

The mean age of red sea urchin harvesters interviewed was 48 (range 44–55, $n=8$). Seven of the 12 respondents were of European descent, two were European, and three were Aboriginal (First Nations, Métis). Respondents have been fishing sea urchins commercially for a mean of 19 years (range 13–28).

Fishery trends

Russian illegal, unreported and unregulated (IUU) fishery

When asked whether the decline in BC sea urchin market value due to Russia's IUU urchin fishery had affected them, almost all (8/12) respondents reported that their wages had declined, they had worked less (2/12), or that they had stopped working in the fishery altogether as a result (2/12). Four respondents mentioned that they had not fished the full quota in years. One mentioned that they felt BC's market value was improving.

Abundance

When asked how the abundance of urchins has changed since they began working in the fishery, all of 11 respondents felt dramatic declines had occurred wherever otters were present. However, opinion was divided on abundance trends in areas were otters had not yet spread: respondents felt that with the exception of otter-impacted areas, abundance had increased somewhat or dramatically (5/11), or had generally stayed the same (2/11). Most of these respondents cited that this was because they had not harvested the entire area quotas in years due to the poor market conditions, which had allowed populations to recover or increase in size. One respondent felt that inside areas (inlets and channels) had seen a decline in urchin abundance but an increase in size, whereas outside areas had higher abundance, but smaller urchins. The remaining four respondents felt that abundance had declined somewhat or dramatically, depending on area. Overfishing, particularly in the North Coast, was the main reason cited for this trend.

Management issues

Sustainability

When asked in an open-ended question to identify what they considered to be the top three problems or challenges currently facing the red sea urchin fishery, most (7/11) respondents reported sea otter predation. Respondents commented that sea otters had decimated sea urchins in the Central Coast and were beginning to decimate areas of the South Coast (e.g. Port Hardy), but had not yet made significant inroads in the North Coast. Only one cited overfishing was a top problem at present. However, the next most cited concern (4/11) was how an improvement in market conditions could lead to overfishing if the fishery started harvesting the full area quotas again. Respondents felt the quotas would have to be lowered to account for depletion of sea urchins by expanding sea otter populations. A number of additional problems were cited by respondents: (1) poor market conditions mean low prices for BC sea urchins (3/11); the owner–operator system – licence holders do not currently have to be harvesters, but licence holders are those with influence in the management process (2/11); and (3) vessel mobility in the North Coast, as compared to the South Coast, was too limited (2/11).

Recommended management measures

When asked in an open-ended question whether there were management measures they thought needed to be taken in the red sea urchin fishery, no one management measure was more cited by respondents ($n=8$; Table B1).

Appendix C. Summary of harvester responses regarding additional sea cucumber fishery issues

Areas with low versus high abundance

Respondents commented that areas with low abundance include the West side of Banks Island, Porcher Island, Trutch Island, Laredo Channel, Barry Inlet, Mathieson Channel, Raymond Passage, the Gulf Islands, and the Juan de Fuca. Conversely, respondents commented that areas with high abundance were McKay Reach, Gil Island, Whale Channel, Haida Gwaii, and Bella Bella.

Table B1
Management measures harvesters ($n=8$) stated they would implement when asked "Are there management measures you think need to be taken to better manage the red sea urchin commercial fishery?" and the frequency of their mention.

Management measure	Frequency
Make mandatory that licence owners be harvesters	2
Greater harvester mobility in the North Coast to prevent overfishing	2
None	2
Lower licence quota	1
Make QMAs smaller	1
Mandatory VMS on each vessel	1
Better marketing of BC product	1
Lack of trust in processors so process locally and grade in front of harvesters	1

Harvestable coastline

Most respondents (10/14) felt more of or the entire coastline should be open to the fishery. However, all elaborated that this was on condition that the rotational harvest be well managed. For example, if there were improved density estimates and sustainable quotas. Two of 14 felt the amount of coastline open should remain as is and two felt more of the coastline should be closed.

No-take reserves

One third of nine respondents felt that no-take reserves were important in maintaining a sustainable fishery and that the number of reserves should be increased, assuming they were chosen for their importance as a source of larvae or rearing ground for juveniles or for their high numbers of productive adults. Another third of respondents felt that no-take reserves were less important in ensuring a sustainable fishery than appropriate quotas and a well-managed rotational harvest. However, some of these respondents cited that maintaining control sites for biological research, rather, was a good reason for increasing the number of reserves. The remaining respondents were not certain how useful no-take reserves were in conserving sea cucumbers.

Enforcement

Almost all respondents (8/9) felt there was sufficient monitoring of fishing fleet activities by DFO. For example, a few respondents elaborated that harvesters generally police each other and are well organised. However, three of these eight respondents felt the use of aquaculture licences to poach wild cucumbers was a growing sustainability problem that DFO needed to address. These three respondents felt that penalties for poaching or for buying poached sea cucumbers were not severe enough, and that buyers should be mandated to report where their purchases were harvested. Only one respondent felt that DFO enforcement was poor, citing lack of work safety monitoring and appropriate penalties for safety violations as the main reason for this.

Aquaculture

Almost all (19/20) respondents were in favour of expanding sea cucumber aquaculture. However, of the 19 respondents in favour of expansion, 12 felt they should do so cautiously because of the unknowns and challenges associated with sea cucumber aquaculture. Example concerns put forth by respondents were how feasible or profitable would it be, as growth rates are unknown; how might it affect wild stocks; and only if poaching of wild stocks using aquaculture licences was closely checked. Further, another three were more in favour of investing in enhancement of wild stocks than aquaculture. Two respondents felt that dry land aquaculture would be the safest. One respondent had no opinion on the topic of aquaculture.

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