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REPORT

Distal impacts of aquarium trade: Exploring the emerging sandhopper (*Orchestoidea tuberculata*) artisanal shore gathering fishery in Chile

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Abstract Artisanal fishery activities support the livelihoods of millions of people worldwide, particularly in developing countries. Within these fisheries, distal global drivers can promote switching between alternative target resources. These drivers can promote the rapid development of new, unregulated and previously unexploited fisheries that pose a threat to the sustainability of ecosystems. In this paper, we describe a new artisanal shore gathering activity that targets a previously unexploited resource: the sandhopper (*Orchestoidea tuberculata*). The activity is driven by aquarium trade demand for food. We used mixed methods to describe the activity, assessed basic socio-economic incentives, and estimated Catches per Unit Effort. Results show that the sandhopper plays an important role for the livelihoods of shore gatherers engaged in the activity. Gatherers have adapted and developed two main extraction methods with different degrees of investment and extraction rates. Furthermore, gatherers have developed local knowledge regarding the ecology and management of the resource. Results show that economic incentives can motivate a rapid expansion of this unregulated activity. Future research gaps and management options to address the development of this fishery are discussed in light of these findings.

Keywords Adaptive capacity · Fishery specialization · Gleaning · New fishery resource · Social–ecological system · Telecoupling

INTRODUCTION

Artisanal fisheries represent an important source of income for millions of residents in coastal communities around the globe, particularly in developing countries (Allison and Ellis 2001; Castilla and Defeo 2001; McClanahan et al. 2009). Fishers often diversify fishing options by transitioning between alternative target resources. While fishery effort allocation is often linked to local factors such as investment costs, demand, yield, and the cost of acquiring expertise (Defeo and Castilla 1998; Salas et al. 2004), the global demand for specific products can incentivize fishers to shift towards targeting new, formerly unexploited resources. The risk of these global drivers relates to overharvesting, especially when fishers target a new resource lacking management history and guidelines (Gelcich et al. 2010, Godoy et al. 2016).

The gathering of species for ornamentation is an area that has recently gotten attention because it drives artisanal fishery effort towards new species (Shuman et al. 2005; Schwerdtner Manez et al. 2014). Although aquarium trade operates at a global scale, it has local ecological impacts (Tissot & Hallacher 2003; Thornhill 2012; Cohen et al. 2013; Dee et al. 2014; Fujita et al. 2014). These impacts may be directly related to harmful practices including species removal, habitat destruction, and biological invasions, such as those reported for the lion fish (*Pterois volitans*/miles complex) linked to aquarium discharge mismanagement (Whitfield et al. 2007). On the other hand, aquarium trade impacts may be indirect, like the targeting of species for aquarium animals' food supply. While the direct effects of ornamental species removal are increasingly being assessed (Thornhill 2012; Schwerdtner Manez et al. 2014), the indirect ripple effects of aquarium trade have not received much attention.

The demand for aquarium food has resulted in a new form of artisanal shore gathering in a place where the aquarium trade had no previous known ecological impacts. Shore gathering (or gleaning) targets sedentary and spatially structured stocks, requiring by nature a different approach to management than commercial fisheries (Castilla and Defeo 2005; Orensanz et al. 2005; Gelcich et al. 2010). In Chile, a new form of shore gathering targeting the amphipod sandhopper *Orchestoidea tuberculata* has developed, beginning in the early 2000s. Sandhopper is extracted, dried, and sold as a food supply for aquarium animals, therefore competing with the imported scuds *Gammarus sp* as a food supply (Araos 2006; ADUANA 2015). Preliminary field observations have shown that artisanal shore gatherers have included sandhopper as a resource in their livelihoods, and have developed local extraction techniques (Araos 2006). However, a more detailed description of the system has not been performed. This artisanal activity provides a unique opportunity to address the management needs of a new fishery and a first step towards identifying indirect ripple effects of aquarium trade.

In this paper, we provide insights on how artisanal shore gatherers have developed a new local shore gathering activity that targets sandhopper. The overall aim is to provide a baseline against which future changes can be quantified and to open ground for local sandhopper management and policy strategies. Specifically, we (a) illustrate the sandhopper extraction system via a description of the new activity and by identifying gatherers' local knowledge, (b) analyze the economic benefits and importance of this activity for the livelihoods of artisanal fishers, and (c) provide insight on future key research questions and the need to start managing this activity.

MATERIALS AND METHODS

Research setting

We assessed the sandhopper extraction process, which uses sand traps, in two neighboring beaches of Region VI of Chile. These beaches called "Las Cruces" (34.55°S; 72.05°W) and "Las Trancas" (34.61°S; 72.04°W) are located on the southern limit of the region near the fishing cove of Bucalemu and are separated by 6.6 km (Fig. 1). We performed field visits between October 2007 and February 2008 and focused on shore gatherers extracting sandhopper (Araos 2015; Gelcich et al. 2013). Shore gatherers are the vast majority of artisanal fishers in this region (Gelcich et al. 2006; Araos 2015). They mainly target brown bulk kelp (*Durvillaea antarctica)* and the red algae (*Mazaella laminaroides)* known locally as 'cochayuyo' and 'luga,' respectively (SERNAPESCA 2012). During the season in which gatherers engage in the sandhopper extraction (September–April), they live with their families in small shelters known as 'rucos,' built near the shore. During the rest of the year, they live in the small town of Bucalemu

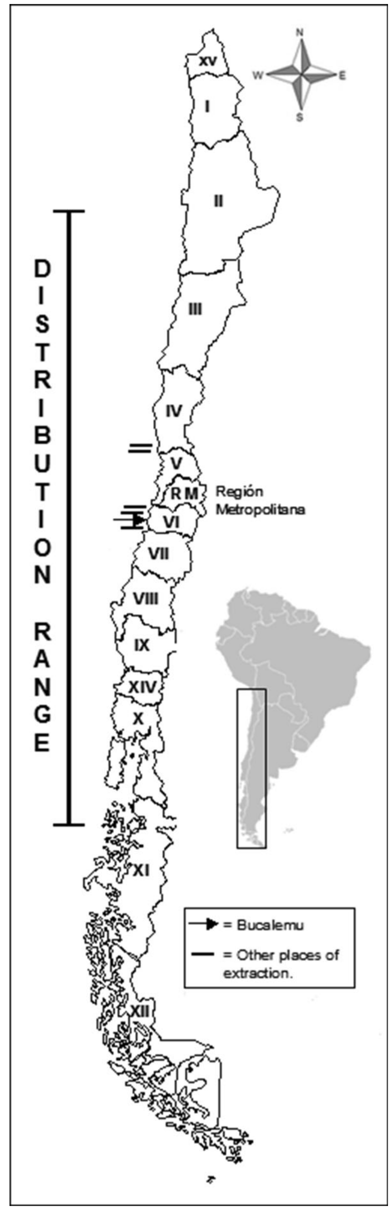

Fig. 1 Map of Chile, showing the location of Bucalemu, administrative regions, and observed places of sandhopper extraction. The distribution range of the sandhopper is based on a new record (Baessolo et al. 2010)

(34.65°S; 72.05°W) which holds a rural fishing cove (Fig. 1). Previous ethnographic work found that gatherers of this Region have a strong cultural connection with the shoreline. In fact, by settling in for seasons in their 'rucos,' linking fishing with other family activities, and with every gatherer knowing each other, there is a high sense of cultural community identity (Recasens 2003; Araos 2015).

The sandhopper being gathered is ovoviviparous, showing direct development (Contreras et al. 2013). It is the predominant species in the upper sandy intertidal zone and distributed along practically all the exposed sandy beach ecosystem of Chile (Jaramillo et al. 2000; Defeo and McLachlan 2005; Duarte et al. 2009; Baessolo et al. 2010). Adult sandhopper length ranges from 15 to 22 mm (Häussermann and Försterra 2009). Sandhopper plays an important ecological role by mobilizing organic matter from algal wracks. They also show cannibalism, where adults, under limited sources of food, prey heavily upon juveniles (Duarte et al. 2010, 2014). Sandhopper presents diel ontogenetic locomotor differences, where adults are more active throughout night, while juveniles are more active at dusk and dawn; probably as a cannibalism avoidance mechanism (Jaramillo et al. 1980; Naylor and Kennedy 2003). Predation from seabirds such as sanderlings (*Calidris alba*) on sandhopper has been reported (Castro et al. 2009).

Field methods

The extraction and management of sandhopper

General methodology The general methodology we used to gain knowledge about the sandhopper gathering extraction process was based on participatory observation coupled with formal and informal interviews distributed throughout four field visits. Our first visit was exploratory in order to get basic knowledge about the sandhopper gathering technique (use of sand traps, see results for details) and commercialization. The other visits were dedicated to measuring catch per unit of effort (CPUE), identifying different gathering techniques, assessing local knowledge, and learning about the economic benefits of this new activity. On each beach, we deployed three transects perpendicular to shore, with a separation of 20 m. On each transect, we measured the beach slope, wave height, and wave period for every meter, starting from the base of the dunes to the swash zone.

Catch per unit of effort Since sandhopper gathering relies on trapping, we weighted sandhopper traps prior to deployment by shore gatherers using a handheld scale with 0.25 g accuracy ($n = 50$). After traps were retrieved, we filtered out deposited sand and weighted the traps again. We calculated the Catch Per Unit of Effort as the average difference between the trap weight after gathering (W_g) and before deployment (W_d). We assumed resting time as constant, based on preliminary statistics (see CPUE section of results).

$$\mathrm{CPUE} = \left(\mathrm{W_g}\right) - \left(\mathrm{W_d}\right)$$

The user, the resource, and economic benefits We interviewed shore gatherers capturing sandhopper between September 2007 and February 2008 ($n = 20$). These interviews were structured according to the information gathered on the first exploratory fieldwork phase, and consisted of 26 items structured into three dimensions: (i) the user, (ii) the resource, and (iii) the economic benefits related to the sandhopper extraction. The interview process was semi-structured and included 19 open-ended questions and 7 Likert-type statements (anchor points: 1 = strongly disagree and 5 = strongly agree). Interviews took place while gatherers deployed or gathered their traps. We performed interviews in Spanish, after an informed consent agreement was signed.

Interviews aimed to measure (a) daily and yearly extraction rates, (b) investment needed to operate in this new activity (in form of capital and time), (c) the economic importance of *O. tuberculata* in gatherers' livelihoods, (d) gatherers' ecological awareness of sandhopper, (e) perceived sustainability of the activity, and (f) parameters that inform the total area of influence of a series of traps (Arena et al. 1994; Gutiérrez et al. 2011). The interviews also allowed us to explore the sandhopper supply chain in Chile.

In addition to the interviews with gatherers, we performed open-ended interviews with representatives of two companies that commercialize sandhopper in Chile to help us gain knowledge of the market for this resource. We also visited pet shops and online websites to verify the existence of the product on the shelves and obtain the final retail price of the sandhopper as a food supply for aquarium trade.

Statistical analysis

We analyzed data using *R* statistical software. Results obtained from the questionnaires were analyzed with the parametric *t* test and the non-parametric Mann–Whitney *U* test, according to the normality of the data and the nature of the response variable being tested. For comparing the differences in CPUE in the two trap methodologies, we performed a Welch *t* test for comparing two samples.

RESULTS

Sandhopper extraction system description

General description and local knowledge

A total of 20 different shore gatherers were interviewed during the study. In parallel, 50 sand traps (see below) were randomly selected and assessed. Sandhopper extraction is mainly a family activity, where all members are involved in the process. There is no specific division of labor, and a high degree of cooperation is observed. The average age of gatherers (head of households) was 46 years. However, children and elders also participate. On beaches where extractions take place simultaneously by several family groups, there is a division of the beach, where each family extracts in a determined sector. It is clear from the participant observation process that this division represents a way in which gatherers locally assign spatial access for the extraction process, and therefore avoid conflict during extractions.

In general, the deployment of traps for sandhopper consists of (1) making holes in the sand (Fig. 2a), (2) covering them with a 70 × 30 cm polyethylene plastic bag (Fig. 2b) placing brown bulk kelp (*Durvillaea antarctica)* as attractant inside the traps (Fig. 2b, c). We also observed a second technique that substitutes the plastic bag for a plastic bottle. Here, the top of the bottle is cut out, which allows sandhopper to jump in and get trapped inside (Fig. 2c). Both methods have costs and benefits for users (see economic investments section). Traps are deployed throughout the night and collection is made just before dawn. The bag or bottle is drawn out of the dug holes and sandhopper is kept in large sacks until they are cooked in boiling water (Fig. 2d) for 10 min (Fig. 2e), after which they are dried in the sun for two days (Fig. 2f).

Sandhopper extraction only takes place at night. In fact, 100% of the gatherers stated that sandhopper only come out at night. In addition, sand traps are deployed during the lowest tides in order to avoid loss of traps by immersion. This requires knowledge about tide schedules; 100% of the gatherers said that tide height was the most important factor to meet the necessary conditions for trap deployment. Spring tides happening at night allow for 2–3 days of labor every 15 days. During spring tides, the average lowest tide is at 0.2 m and the highest tide is at 1.8 m. Sea conditions allowing traps are deployed at dusk. Gatherers showed to have significant knowledge about the factors that affect sandhopper abundance: 35.7% said abundance was driven by the amount of stranded algae in the beach, 23.9% by sand color, 18.9% by sand permeability, and 18.9% by sand size.

In essence, gatherers have developed local knowledge of the biophysical system through the capturing ritual:

> "Sandhopper is seen more during the night, so we started setting traps at night…. After losing a significant amount of traps, we realized we needed to work on the lowest tides of the month. Working at night and during the lowest tides reduced how many days we could work capturing sandhopper, but extractions were more efficient and less traps were lost"
>
> (Gatherer from Las Cruces, November 2007).

Fig. 2 Extraction process: **a** Sandhopper *Orchestoidea tuberculata*, **b** deployment of traps, **c** plastic bag trap (specialist technique), **d** plastic bottle trap (non-specialist technique), **e** gathering of the extraction, **f** boiling, **g** sun drying

Catch Per Unit of Effort, daily, and yearly extraction rates

Basic beach morphometrics showed similar characteristics for both the beaches sampled (Table 1). The average resting time for the sand traps (4.6 ± 0.21 h) was similar for both groups ($t_{(48)} = 0.75$, $P = 0.457$), and was assumed constant for CPUE estimation. The catch per unit of effort (CPUE) was significantly different for both traps, being higher in the group using plastic bags in their traps (*t* test: $t_{48} = 4.854$, $P \leq 0.001$). This group of gatherers showed an average CPUE per night of 1.225 ± 0.28 kg trap^{-1} (mean ± SD), while the group that uses plastic bottles showed an CPUE of 0.513 ± 0.11 kg trap^{-1}, approximately 40% less. On the other hand, there was no statistically significant difference on the number of sand traps deployed daily for each group; interviews showed that on average 42.4 ± 3.11 plastic bags and 40.9 ± 2.81 plastic bottles were deployed daily (*t* test: $t_{18} = 1.949$, $P = 0.068$). There were also no statistically significant differences between groups regarding the distance between deployed sand traps (3.58 ± 1.59 m), the distance from other gatherers' deployed sand traps (138 ± 53 m), and the perceived area of influence of each sand trap (18 ± 7.27 m). The last four parameters have been shown to inform the 'effective fishing area' by trap gear in deep-sea crab fisheries (Arena et al. 1994; Gutiérrez et al. 2011). The group that uses plastic bag traps, with significantly higher extraction rates under the same effort, is hereafter categorized as the specialist (S) group; while the group using plastic bottles is referred to as the non-specialist (NS) group. Both groups were found in both beaches in practically equal proportions.

Interviews showed that specialist gatherers consistently had significantly higher extraction levels than the non-specialists. Interviews showed that they are receiving approximately a fourfold extraction per year compared to the non-specialist group (t-test: $t_{18} = 7.163$, $P < 0.001$, Fig. 3b). The same difference was observed on the daily extraction rate, being three times larger for the specialist group (*t* test: $t_{18} = 4.257$, $P < 0.001$, Fig. 3a). Moreover, statistically significant differences were observed on the maximum extraction each group has perceived daily (*t* test:

Table 1 Basic beach morphometry for both sampled beaches. Mean and SD (in parenthesis, italic) are reported. Three transects were deployed parallel to the shore, with a distance of 20 m between them. Mean slope, wave height, and wave period was measured for every meter, starting in the dunes and ending in the swash zone ($n = 50$)

Sector	Mean slope (cm/m)	Mean wave height (cm)	Mean wave period (s)
Las Trancas	7.37 (*7.06*)	183.5 (*8.26*)	15.3 (*0.6*)
Las Cruces	8,14 (*8.46*)	179.9 (*4.94*)	15 (*1*)

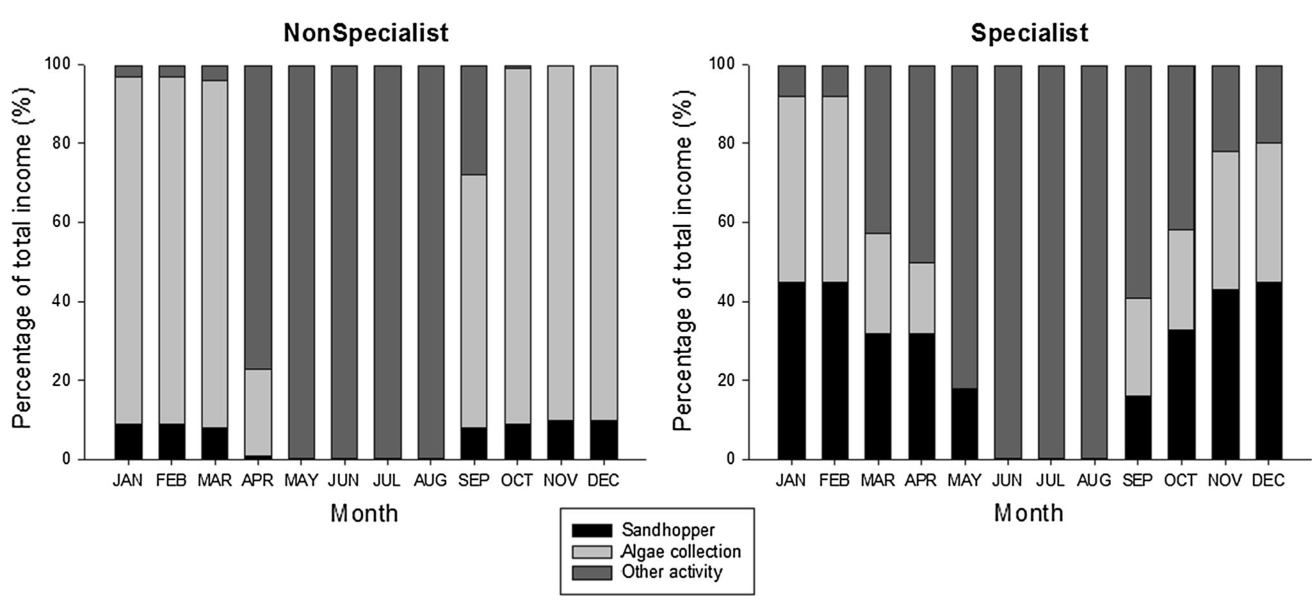

Fig. 3 Economic importance of sandhopper activity compared to the gathering of algae according to the percentage of total monthly income for (i) Non-specialists using plastic bottles and (ii) Specialists using plastic bags

$t_{18} = 3.269$, $P = 0.006$) and yearly (t test: $t_{18} = 7.163$, $P < 0.001$).

Livelihood importance and perceived sustainability

All interviewed sandhopper gatherers stated that their main activity was seaweed shore collection. When asked about the main resource they extract, 73.3% stated it was seaweed and only 13.3% stated it was sandhopper. As for the second resource in terms of importance, 46.7% gatherers stated it was sandhopper, and 33.3% benthic intertidal shellfish. Gatherers tended to disagree that the extraction technique considers the resource's sustainability (Table 2). Furthermore, the majority of gatherers stated that the sandhopper populations have decreased since first extractions began (Table 2). This awareness of population decrease can be observed in the following quote:

> "We are concerned that each year we see less sandhopper on the beach. Having a good sale price, more people are now extracting sandhopper and we fear that the resource will be significantly reduced."
> (Gatherer in Las Trancas, November 2007)

Economic investment and benefits

Interviews showed that specialist and non-specialist sandhopper gatherers work around the same months each year. Both groups engage in the activity on average 5 days per year, and 12 days per month (t test: $t_{18} = -0.565$, $P = 0.579$). However, the yearly investment in the specialist groups was on average USD 6.2 compared to non-specialists who only invested half of this amount. The difference lies in specialists having to bury plastic bags for their traps, while non-specialists recycle water gallons (Fig. 2b, c). The physical effort is also considerably higher for specialist gatherers; they have to bury the plastic bags in the sand, while non-specialists just place the traps over the sand (Fig. 2b, c). Despite these differences, all gatherers practically perceived no problems associated with the activity (Table 2).

The average monthly income obtained exclusively from the sandhopper gathering was significantly higher in specialized gatherers, earning 5.3 times more monthly income from this activity than non-specialists (t test: $t_{18} = 3.683$, $P = 0.003$). The price at which the sandhopper sold was significantly higher in the specialist group. It is important to highlight that the total average monthly income of both groups was similar. The average monthly income is represented by the total income from sandhopper activity plus the income from seaweed collection and other fishery and non-fishery activities. Specialists earn 0.696 ± 0.055 monthly Chilean minimum wages (of 2007), and non-specialists earned 0.588 ± 0.043 monthly minimum wages (t test: $t_{18} = 1.59$, $P = 0.136$). In terms of dependency on different resources, specialists earned 45.8% of their yearly income from seaweed extraction and 43.3% from the sandhopper activity. As for non-specialists, seaweed collection represented the most important source of income, at 87.2% of the total (Fig. 4). Shore gatherers stated that the main drivers to begin extractions of sandhopper were to increase personal profits (57.9%) and the fact that sandhopper was a well-paid resource (38.6%). Gatherers have also perceived an increase in sandhopper price over time (Table 2).

Interviews with sandhopper retailers showed that the volume of sandhopper being sold nationally is approximately 10 000–15 500 dry kg year^{-1}. Specialist gatherers were shown to have an enhanced insight on the volume of sandhopper being traded nationally. All shore gatherers

Table 2 Mean scores (±SE) of Likert-type statements regarding different dimensions of the new sandhopper activity. Likert scale anchor points represent 1 = strongly disagree to 5 = strongly agree. % of respondents that agree were calculated by adding 4 and 5 scores. Neither agree or disagree are individuals that gave a 3 response. Finally, individuals considered to disagree gave a 1 or 2 answer

Likert-scale questions	Likert score (±SE)	% Agree	% Neither agree nor disagree	% Disagree
Ecological awareness				
There is sandhopper in every beach	1.66 (0.27)	15	0	85
Tidal height at deployment affect extractions	3.80 (0.45)	*95*	0	5
Amount of algae placed in traps affects extractions	4.00 (0.39)	75	20	5
Activity's sustainability				
Sandhopper abundance has decreased since extractions began	4.53 (0.22)	80	0	20
Extraction techniques consider the resource's sustainability	3.47 (0.45)	25	25	50
Commercial insight				
Your sandhopper price has increased in time	4.73 (0.20)	95	0	5
There are no problems associated with the activity	4.47 (0.27)	95	0	5

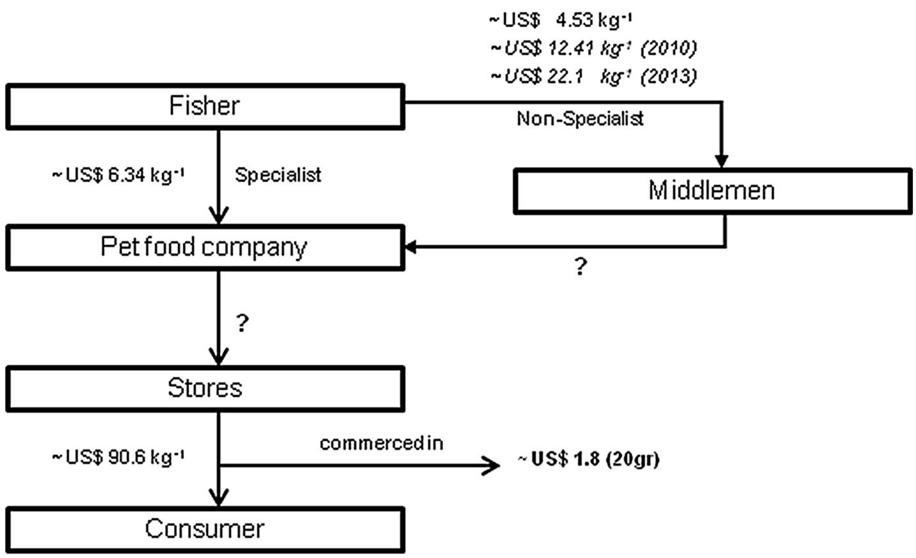

Fig. 4 Sandhopper marketing chain in Chile. All the prices are from the interviews held in 2007, except the updated sale price from gatherers to middlemen represented in italic. These were obtained from posterior fieldtrips in 2010 and 2013. Specialist gatherers using plastic bags directly sell their extraction, Non-specialists gatherers using plastic bottle sell it via middlemen

that gave an estimate similar to the sandhopper retailers were from the specialist group. In terms of final product awareness, 93% of gatherers noted that the final use for the sandhopper was for feeding aquarium animals. Personal communications with the regional fisheries service stated that there are a total of 16 gatherers in Las Cruces and 12 in Las Trancas settlements.

Commercialization chain

The sandhopper commercialization chain in Chile features few levels (Fig. 4). On the foundation are the sandhopper gatherers described in this paper. In some cases, the gatherers sell the catch to a middleman at an approximate price of USD 4.5 dry kg^{-1} (Fig. 4). In other cases, the specialist group sells the extraction directly to the processing company at USD 6.3 dry kg^{-1}. Given the informality of the activity, we were not able to determine the sale price of the processing companies to the pet shops. The retail price for the sandhopper was USD 90.6 dry kg^{-1}, commercialized in 20 g packages sold at USD 1.8 each. Thus, price increased 1400% from the price at which gatherers sell their extraction to the price which the consumer pays for the product in the stores (Fig. 4). Sandhopper bulk price has increased steadily in the last 10 years (Table 2, Fig. 4).

DISCUSSION

Sandhopper gathering in Chile represents a ripple effect of the global aquarium trade, since it serves as food supply for imported ornamental aquarium animals. The former products for aquarium food supply in Chile were imported scuds *Gammarus spp* (ADUANA 2015). Artisanal shore gatherers started targeting sandhopper in the mid 2000s, leading to the first observations of sandhopper gathering on beaches in central Chile (Araos 2006; SERNAPESCA 2012). Our results show that with time, this activity has become an important source of income for the livelihoods of some coastal shore gatherers in central Chile. Being a new activity, understanding the sandhopper extraction process is critical to inform future management.

Shore gatherers engaging in this activity show considerable adaptive learning capacity. This is specially the case for the specialists, who have a significantly higher gathering rate and revenue (Figs. 3, 4). Gatherers have shifted their extraction patterns in order to collect sandhopper at night (Gelcich et al. 2010; Araos 2015). This matches the circadian locomotor activity of sandhopper (Jaramillo et al. 1980; Kennedy et al. 2000). The existence of local knowledge is an important part of this learning process, facilitated by previous awareness of tides and species interactions (Table 2; Araos 2015). Traps are highly selective in contrast to, for example, the mechanical and manual harvesting of lugworms *Arenicola marina* which have been shown to have severe impacts on macroinfauna (van den Heiligenberg 1986) or when compared to cyanide fishing (Rubec et al. 2000). Gatherers' local knowledge also refers to a broad socio-cultural relation to the entire coastal environment, which represents the cornerstone of their livelihood and wellbeing that goes beyond the economic use of a resource (Araos 2015; Gelcich et al. 2017). The sandhopper extraction activity thus poses the challenge of how to determine sustainable extraction levels.

The ecological effects of sandhopper gathering are still unknown and were not assessed in this study. However, we suggest that a precautionary approach must be taken, given that there is a general perception of populations' decline since gathering began (Table 2). Sandhopper has a direct life cycle, making it highly vulnerable to depletion and/or local extirpations (Naylor and Kennedy 2003; Contreras et al. 2013). This is critical since sandhopper may be an important species in coastal trophic food webs (Macneil et al. 1999; Castro et al. 2009). Given that sandhopper forages on stranded algal wrecks, it mobilizes the organic matter to upper levels on the food web (Castro et al. 2009; Duarte et al. 2009, 2010). Consequently, human gathering of sandhopper may alter the intertidal sandy beach food web and community structure. It is also important to note that macroinfauna in sandy beaches has been described to serve as ecosystem engineers (Tamaki and Ingole 1993; Botto and Iribarne 1999).

Our results highlight the existence of some efficient management practices that could serve as basic building blocks to initiate regulations. Gatherers deploy traps after dusk and retrieve them before dawn, avoiding gathering in times of highest juvenile activity (Jaramillo et al. 1980; Kennedy et al. 2000). They also rotate sectors of the beach, apparently giving some time for sandhopper to recover. Local knowledge and informal management practices are important elements which can contribute to building sustainable management practices (Berkes et al. 2000). This is critical for sandhopper populations' sustainability, since extraction of non-reproductive juveniles could jeopardize populations (Naylor and Kennedy 2003). The importance of understanding and integrating diel or tidal ontogenetic changes in behavior into management practices of sandy beaches appears crucial for the sustainability of the sandy beach resources (Naylor and Kennedy 2003). Emphasis on these aspects should inform formal management practices.

Results show that this new resource plays an important role in the livelihoods in a group of artisanal shore gatherers. The activity operates under an open access regime and increasingly receives new entrants. Sandhopper extraction does not require making a significant monetary and time investment, hence, there is a potential for overexploitation. The low operational and opportunity costs required coupled with the significant revenue represent important incentives to enter this new activity. This trend has already led to sustainability issues in northern Chile, where economic incentives from international markets motivated artisanal divers to allocate fishing effort exclusively to *Octopus mimus*, switching from a generalist multi-species benthic fishery. The result was a fourfold increase in trips and sevenfold increase in effort, jeopardizing the sustainability of the fishery (Defeo and Castilla 1998).

Given that the economic incentives from this activity are considerably high, management plans and official sandhopper gathering statistics are necessary for an efficient use and conservation of sandhopper. The first official statistics taken by SERNAPESCA in 2012 show a total yearly gathering volume in Region VI of approximately 2 tons (SERNAPESCA 2012). This is probably a serious underestimation considering that each specialist gatherer extracts approximately 1200 wet kg year^{-1}. With these results, only 2 specialist gatherers would surpass this volume. Additionally, the activity takes place across the entire Region VI. Hence, the yearly gathered volume could be considerably higher. In terms of CPUE, during 2014 and 2015, the national fisheries service estimated an average daily CPUE of 59.9 ± 0.77 wet kg day^{-1} (SERNAPESCA 2014, $n = 80$). This is similar to the daily CPUE for specialist gatherers in our study (Fig. 3a).

A caveat in our study is that we did not take into account the effect of different beach morphodynamics in catch levels. Literature shows that beach morphodynamic has an effect on macroinfauna abundance and community structure (McLachlan et al. 1993; Gómez and Defeo 1999; Jaramillo et al. 2000). In essence, management should be informed by future research that performs a multifactorial experimental design to test the effect of (i) beach morphodynamics, (ii) season of the year, (iii) sand trap type, and (iv) their interactions on gathering levels. This design would benefit by performing an assessment with a broader time and spatial scale. Future research to inform management should also consider the ecological effects of local sandhopper extirpations (Naylor and Kennedy 2003; Defeo and McLachlan 2005; Defeo et al. 2009). There is also a need to integrate stock assessments in beaches where sandhopper is being gathered in order to better inform sustainable gathering levels (Hilborn and Walters 1992). Ideally, research should integrate stochastic processes into future assessments, in order to begin accounting for the uncertainty inherent to coastal marine resources (Clark and Kirkwood 1986; Lima et al. 2000).

Management of artisanal fisheries at appropriate spatial scales has been proposed as a critical element of success (Freire & García-Allut 2000; Berkes 2004). One possibility to initiate the management of sandhopper in Chile builds upon a new policy in the Chilean fishieres and aquaculture law (number: 20 657). The management plan policy allows the creation of management plans of a species, or a group of species within a bay, a region, or a group of regions where de facto open access dominates (Gelcich 2014). This new policy could allow the correct institutional setting to begin a novel management partnership among the users of this new resource and management institutions. Hopefully, the information and warning signals in this paper may trigger and support the necessary policy discussions to regulate this activity under this novel policy instrument.

CONCLUSION

The global increase in aquarium trade has provided economic incentives for shore gatherers in Chile to include sandhopper as a source of income into their livelihoods. Results from this paper inform on novel distal ripple effects of Aquarium trade. A specialized group of gatherers has further adapted to this new resource by optimizing the extraction and maximizing revenue. This specialized group of gatherers has diversified their sources of income, no longer depending exclusively on seaweed harvest. Through sandhopper gathering, the users have been able to develop knowledge on the species' natural history, ecology, and management. This includes insights on gathering only when adults are active, avoiding the gathering of juveniles and a gathering method that solely extracts the targeted resource. Gatherers also rotate sectors of the beach to avoid conflict in resource use. Assessments of the effects of rotating beaches, along with detailed sandhopper population and landing assessments in targeted beaches are critical elements which must be assessed. Further research also needs to focus on factors that influence catch levels under different beach conditions. One example would be an in-depth assessment of the role and interaction of beach morphology, seasons, and sand-trap type on CPUE. This paper is the first scientific analysis of the sandhopper shore gathering activity and provides early warning signals for management. The ecological effects of sandhopper extirpations are unknown to date and should be assessed in the future. This highly profitable resource is currently unregulated and is in need of urgent attention.

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