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Trends in small-scale artisanal fishing of sea cucumbers in Oceania

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ABSTRACT

Multi-species sea cucumber fisheries in Oceania involve vast numbers of small-scale fishers exploiting stocks on coral reefs and tropical lagoons. Fishery development measures might need to be specific to locations or fisher groups, and regulations should be appropriate to fishing activities. To understand fishing among countries, locations, gender and age, we conducted questionnaire-based interviews of 479 sea cucumber fishers in Fiji, Kiribati, New Caledonia and Tonga. Fishers included youth and elderly, and the average age within countries was 36–42 years. Women commonly gleaned sea cucumbers from shallow habitats and dived for them in some countries. Although spatially variable, our results indicate intense fishing pressure based on high trip frequencies and fishing effort. Catch-per-unit-effort (CPUE) differed significantly among countries and locations, and fishers on some islands caught high numbers of low-value species. Young fishers went fishing more often, but age did not affect fishing effort and CPUE. Fishers collected a wide range of sea cucumbers, and up to 27 species were harvested in Fiji. Species composition in catches differed significantly among countries and between genders; women usually harvest species typical of shallower reef habitats. Fishers tended to view stocks as declining or greatly over-exploited. Based on fisher knowledge, recent catch rates for an average fishing day have declined by 33–92% across the study countries compared to 10+ years in the past. Our study shows that fishing modes, catch rates and catch composition in small-scale fisheries can be highly context-dependent. Management measures and interventions to support fisher livelihoods must consider gender differences and location-specific fishing activities. Sharp declines in catch rates over time in all countries, fisher perceptions of resource trajectories, and a predominance of low-value species in present-day harvests, provide strong evidence of widespread over-exploitation.

1. Introduction

1.1. Small-scale fisheries and exploitation of reef invertebrates worldwide

Small-scale fishing for fish and invertebrates has occurred for millennia (Pinnegar and Engelhard, 2008). Small-scale fisheries (SSFs) employ more than 90% of fishers worldwide (FAO, 2012). SSFs in developing countries produce more fish than large-scale fisheries (Mills et al., 2011) and contribute about one-quarter of all global fisheries catches (Pauly and Charles, 2015). In developing countries, SSFs play a vital role in food and nutritional security (Bell et al., 2009; FAO, 2012; Kawarazuka and Béné, 2010; Zeller et al., 2007) and are a source of employment to help alleviate poverty (Allison and Ellis, 2001; Béné et al., 2010).

Although termed 'small-scale', based on the use of simple fishing gears and small vessels, the environmental footprint of SSFs can be substantial (Kittinger, 2013). In the Pacific islands, captures from artisanal fishers appear to have declined by almost half in the past two decades (Zeller et al., 2015). Over-exploitation in small-scale fisheries is a conservation concern globally, and has placed some tropical invertebrates at risk of extinction (Kemp et al., 2012; Purcell et al., 2014b). Understanding fishers, fishing rates and captures in SSFs should be integral to the development of responsible fishery management plans (Friedman et al., 2008), such as restricting catches, numbers of fishers or fishing gears.

Invertebrates are the most economically important inshore fisheries resources in the Pacific Islands (Dalzell et al., 1996). Fishing

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methods can be variable in small-scale invertebrate fisheries and involve a range of fishing gears (Castilla and Defeo, 2001; Leiva and Castilla, 2001; Toral-Granda et al., 2008). Women often play significant roles in artisanal invertebrate fisheries (Crawford et al., 2010; Harper et al., 2013; Kronen, 2002; Lambeth et al., 2014), and may differ from men in their catch rates, fishing grounds and species harvested (Fröcklin et al., 2014; Lambeth et al., 2014).

Increasing fishing pressure on invertebrate fisheries has resulted in declining stocks and catches of many groups such as octopi and echinoderms (Anderson et al., 2011b). Understanding changes in catch rates over time is important for conservation and fishery management measures but such data need careful interpretation because fishers may shift to new fishing grounds or lower-value species (Neis et al., 1999). Fisher knowledge of past catch rates contribute to fishery diagnosis and can put current-day catches into context (Ainsworth et al., 2008; Rochet et al., 2008; Sáenz-Arroyo et al., 2005).

1.2. Exploitation of tropical sea cucumbers

Sea cucumbers are harvested in more than 70 countries worldwide, primarily in small-scale fisheries using artisanal methods (Purcell et al., 2013). In tropical waters they are commonly collected by hand on shallow coral reefs and inshore sandy habitats. The tropical fisheries involve multiple species, predominantly from the order Aspidochirotida (Purcell et al., 2013; Toral-Granda et al., 2008). The vast majority of harvested sea cucumbers are exported to Asian seafood markets in the dried form, called beche-de-mer.

Owing to their high economic value (Purcell et al., 2014b) and ease of storage and transport, sea cucumbers have been overexploited throughout most tropical fisheries (Anderson et al., 2011a; Purcell et al., 2013). Fishing methods, usually gleaning, breath-hold diving and SCUBA diving, vary among countries and women and children are involved in some fisheries (Choo, 2008; Conand, 2008; Eriksson et al., 2015a; Kinch et al., 2008b; Muthiga and Conand, 2014). Stock status is often inferred from data on exports (Anderson et al., 2011a; Conand, 1990; Kinch et al., 2008b), or assessed through underwater population surveys (e.g. Cariglia et al., 2013; Conand, 1989; Dissanayake and Stefansson, 2010; Eriksson et al., 2015b; Friedman et al., 2011; Purcell et al., 2009; Shepherd et al., 2004; Skewes et al., 2010). Few studies have assessed sea cucumber fisheries using fisher knowledge and socioeconomic data (e.g., Conand and Muthiga, 2007; Eriksson et al., 2012; Ochiewo et al., 2010).

In Oceania (central-western Pacific), sea cucumbers have been exploited as a high-value export commodity for at least 170 years (Conand, 1990; Kinch et al., 2008b). Although the fisheries are predominantly artisanal, exploitation in the Pacific Islands is vast and there are at least 300,000 fishers (Table S1 in Purcell et al., 2013; and considering data gaps). Declining stocks have prompted management agencies to set moratoria in many countries and, at the time of our field work, Fiji, Kiribati, Tonga and New Caledonia were among the few Oceania fisheries still permitting exports of beche-de-mer (Pakoa and Bertram, 2013; Purcell et al., 2014a). In the past couple years, some fisheries, such as in Vanautu, have re- opened with new management arrangements (Léopold et al., 2015).

1.3. Purpose and significance of this study

Understanding heterogeneity in fishers and their fishing practices is important for resource management (Muallil et al., 2013; Muthiga and Conand, 2014). Management of coastal Pacific Island fisheries requires a hierarchical approach (Kronen et al., 2010), thus information about fishing at national and sub-national scales is needed. Here, we examine variations in fishing effort, targeted species and catch rates within and among four Pacific Island countries (New Caledonia, Kiribati, Tonga, Fiji) using responses from interviewed fishers. This paper examines differences in fishing activities among these small-scale fisheries and explores the implications to fishery management. Our sampling design allowed us to examine heterogeneity in fishing activities across countries and locations within countries, and potential relationships with fisher age and fishing experience. Women were unequally represented among the fisher groups, locations and countries, so our study offers a modest assessment of gender variation in these fisheries. We further aimed to use several lines of evidence from the surveys to infer status of stocks in these four countries.

2. Materials and methods

2.1. Study locations

The study was conducted in Fiji, New Caledonia (Melanesia), Kiribati (Micronesia) and Tonga (Polynesia) (Fig. 1). In consultation with national or provincial fishery authorities, we selected locations (provinces or island groups) within each country that were important to the sea cucumber fisheries and known to have active fishing (Supplementary material, Table S1). Generally, we visited 3–6 villages within each location in each country. Within locations, villages were chosen where sea cucumber fishing was active.

Interviews with fishers in New Caledonia were conducted from Aug–Dec 2007 (Purcell et al., 2009). Interviews in Tonga and Kiribati were done during May–Oct 2011, and those in Fiji were conducted in Feb–Sept 2014. Despite the 7-year gap between surveys in New Caledonia and Fiji, fishing and exports in these four countries operate independently and the species caught and exported from New Caledonia were the same as those from Fiji 7 years later. Nonetheless, we interpret inter-country comparisons tentatively. One to two weeks were spent in each location within countries, depending on site accessibility and the number of interviewers.

In New Caledonia, compressed-air diving and night diving were banned, and there were some minimum size limits imposed for certain species (Purcell et al., 2009). Recent community-based management systems concern only one community in a small section of the overall fishery (Léopold et al., 2013). In Kiribati, there were no fishery regulations, and virtually no marine reserves existed at the study locations. In Tonga, a moratorium on all sea cucumber harvests had been imposed from 1997 to 2007, and thereafter fishing was regulated by a ban on compressed-air diving, size limits and export quotas (Pakoa et al., 2013b). In Fiji, fishing for sea cucumbers is regulated by a single size limit across all species, and SCUBA diving was permitted only for authorised communities (Pakoa et al., 2013a; Ram et al., 2016). In all countries, community-based management and co-management arrangements related to a minor part of the fishery or were non-existent.

2.2. Survey methodology and data collection

On average, five fishers were interviewed per village, although we only found one or two sea cucumber fishers in some villages. We consulted village elders to find sea cucumber fishers and used key informants and a 'snowball' technique (Cinner, 2005; Henry, 1990) to find other sea cucumber fishers. Our sampling took a gender-inclusive approach (Kleiber et al., 2014) by interviewing women fishers where possible. Otherwise, we told villagers that fishers could be young or old, part-time or full-time, and that the fishing mode did not matter for sampling.

Interviews were predominantly at fishers' homes or in open places within villages, and followed ethics approval and

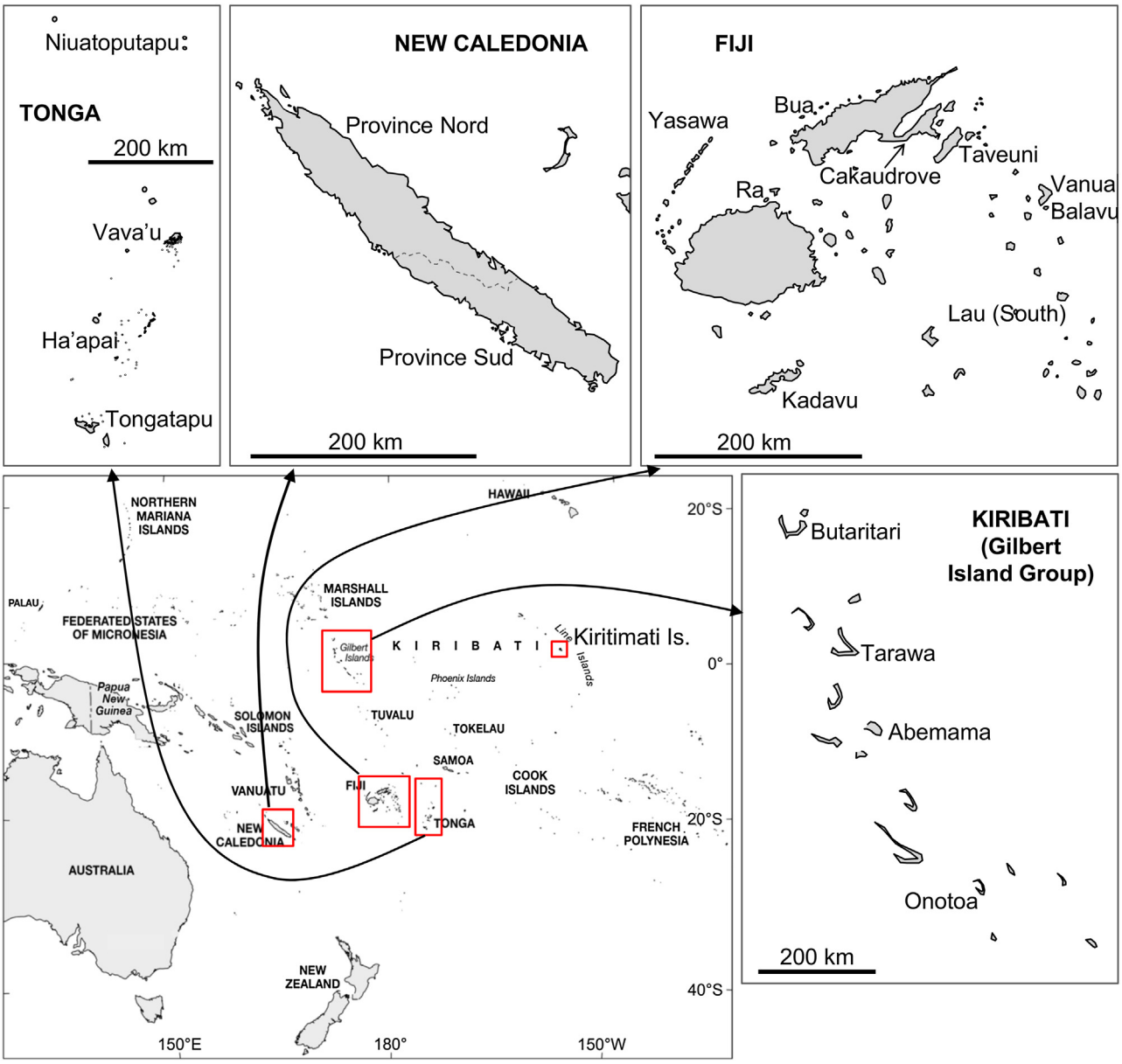

Fig. 1. Map of the central-western Pacific showing the four study countries. Some other island countries are unlabelled. Individual maps show the study locations within each country; Kiritimati Island in the Line Islands Group of Kiribati was also a study location.

procedures.[1] The interviews entailed researchers asking fishers structured questions from the questionnaire (Fig. 2a,b; Supplementary material, S1). Questions were often repeated or asked in an alternative way to validate that fishers understood the questions. The interviews were conducted by national researchers or by a foreign researcher with an interpreter (for SWP), and generally took 40–60 min.

The questionnaire for fishers in New Caledonia is provided by Purcell et al. (2009) and follows advice by Kronen et al. (2007). For the other countries, we adapted that questionnaire by adding and removing certain questions. We used photographic identification sheets to confirm local species names with fishers. The questionnaires determined the age and gender of respondents and posed questions about their fishing activities, fishing methods, catch, perception about the resource state and knowledge about past catches. We were explicit to fishers that fishing effort was the average number of hours they spent in the water searching for the animals per day. Extra questions were asked to confirm that responses were whole pieces and that catches were only what the individual fisher themselves caught. In New Caledonia, fishers replied in weights to this question, so we multiplied those data by 0.832 to convert to estimates of number of individuals, based on landing data on seven species in New Caledonia (S. Purcell, unpubl. data).

[1] Questionnaire-based surveys were approved (Southern Cross University: ECN-13 -279) for ethical human research and overseas research in accord with the Australian National Statement on Ethical Conduct in Human Research 2007. In Fiji, additional approval was granted by the Ministry of Education (approval RA01/14), whereas in Tonga and Kiribati national approval for ethics in human research are lacking so the surveys were simply endorsed by national fisheries ministries. We provided information sheets to fishers about the project, and fishers were informed about the funding, research uses of data, and that their responses were voluntary and confidential. Verbal or written consent was then obtained for the interviews.

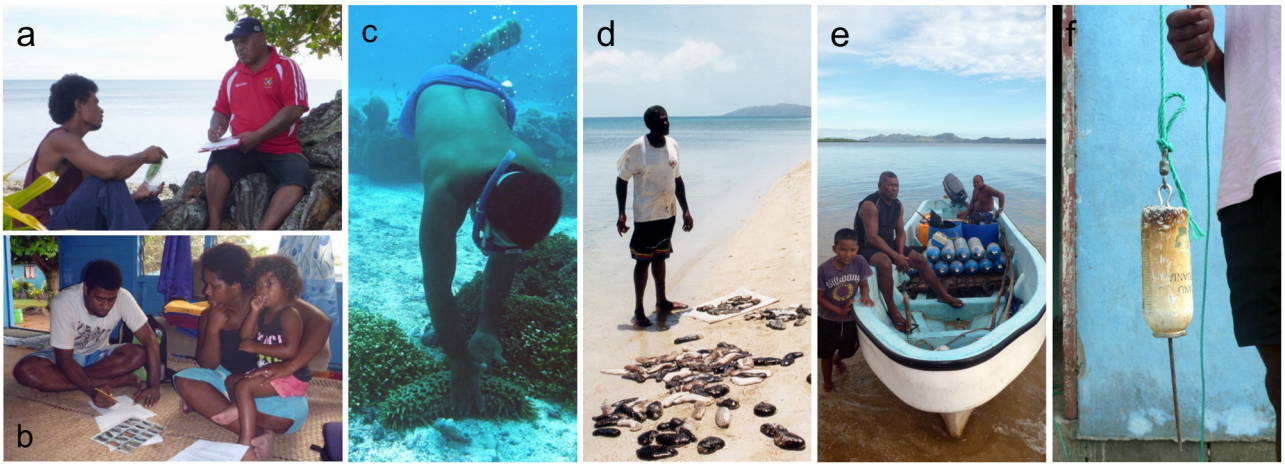

Fig. 2. Fisher surveys and sea cucumber fishing. (a,b) Interview-based survey of a male sea cucumber fisher in Tonga and a female fisher in Fiji. (c) Fisher in Kiribati collecting a prickly redfish *Thelenota ananas* by free-diving with simple gear. (d) Fisher in New Caledonia with catch of assorted sea cucumber species. (e) Sea cucumber fishers with SCUBA tanks and a typical 6-m boat with 40 hp engine at Bua Province, Fiji. (f) A 'lead bomb' is used by divers to impale sea cucumbers, which are lifted up from deep waters. Photos: SW Purcell.

We asked fishers in Fiji, Kiribati and Tonga about how frequently they caught 22 species of sea cucumber. For each species, they were asked whether they caught it often, sometimes, seldom or never, and we ranked responses 3, 2, 1, 0, respectively, and asked for a spread of responses. Fishers did not distinguish between *Stichopus horrens, S. naso* and *S. monotuberculatus*, so these are pooled in this study, and likewise for *Bohadschia argus* and *B. ocellata*. A few other species were very occasionally harvested in Fiji and Tonga but were not part of our questionnaire data (see Section 3).

Fishers were asked about their view of current trends in stock abundance, and reasons if they responded that stocks were declining or depleted. The reasons proposed to fishers included the number of fishers, fishing intensity in the past, a change in fishing gears, natural change and pollution.

2.3. Statistical analyses

To facilitate analyses across countries, we pooled data from surveys among fishers within locations for each country owing to small sample sizes in some villages. This is a statistical approximation for locations, and was also appropriate for management implications, since management measures in the different countries (apart from isolated cases such as reported by Léopold et al. (2013)) currently operate at the national or provincial/island level, not to the resolution of villages. Mixed-model General Linear Model (GLM) analyses using SPSS® software were used to test for differences in the frequency at which fishers went fishing (d week^{-1}), fishing effort (h day^{-1}) and round-trip travel time to fishing sites (h trip^{-1}). To improve homoscedasticity, data on fishing frequency and effort were square-root transformed, and data on travel times were transformed by $\mathrm{Log}_{10}(x+1)$. Country and gender were fixed factors, location within country was a random (nested) factor, and fisher age and years of fishing sea cucumbers were the covariates. Q-Q plots indicated that distributions were close to normal, except for travel times. Levene's test showed that variances were heterogenous among groups, but the tests should be robust due to the large sample sizes (Underwood, 1997). We opted to retain a parametric approach to allow simultaneous testing of multiple factors and potentially interacting variables, but infer marginally-significant ($p = 0.05–0.01$) results circumspectly in order to minimise the risk of Type I errors.

We derived catch per unit effort (CPUE) by dividing the average number of sea cucumbers that fishers said they caught on average per day by the average number of hours they spent in the water fishing. We omitted CPUE data from Fiji, Kiribati and Tonga for cases in which fishers reported average daily catch in kilograms or number of buckets. The CPUE data were $\mathrm{Log}_{10}(x+1)$ transformed prior to the same GLM analyses as outlined above. Data were normally distributed but heteroscedastic, so our inferences about marginally-significant were tentative, as discussed.

We asked fishers how many sea cucumbers they caught on an average day in the past, around when they had first started fishing, and how long ago that was. Dividing the past (recalled) catch rates by current catch rates provides a proportional difference for each fisher, referenced to a number of years in the past. We plotted those data and analysed the linear relationships for each country, logically forcing the intercept through 1.

Multivariate analyses on the ranked frequency of capture for 22 sea cucumber species from Tonga, Kiribati and Fiji were conducted using PRIMER-6 software. Similarity of Percentages (SIMPER) analyses, using a cut-off at 50% similarity contribution, revealed which species were most influential in distinguishing the species caught by fishers of a particular country and gender. We used Bray Curtis similarity matrix on untransformed data and performed a permu-

Table 1
General characteristics of respondents. Superscripted numbers are standard deviations of the means.

Location	Number of respondents (n)	Average age	Age range	% Males	Av. Experience (years fishing)
Kiribati	84	36 ^{11}	17–68	99	5 ^{6}
Tonga	134	40 ^{10}	15–67	81	7 ^{7}
Fiji	235	38 ^{11}	18–73	74	11 ^{9}
New Cal.	26	42 ^{12}	19–67	85	8 ^{9}

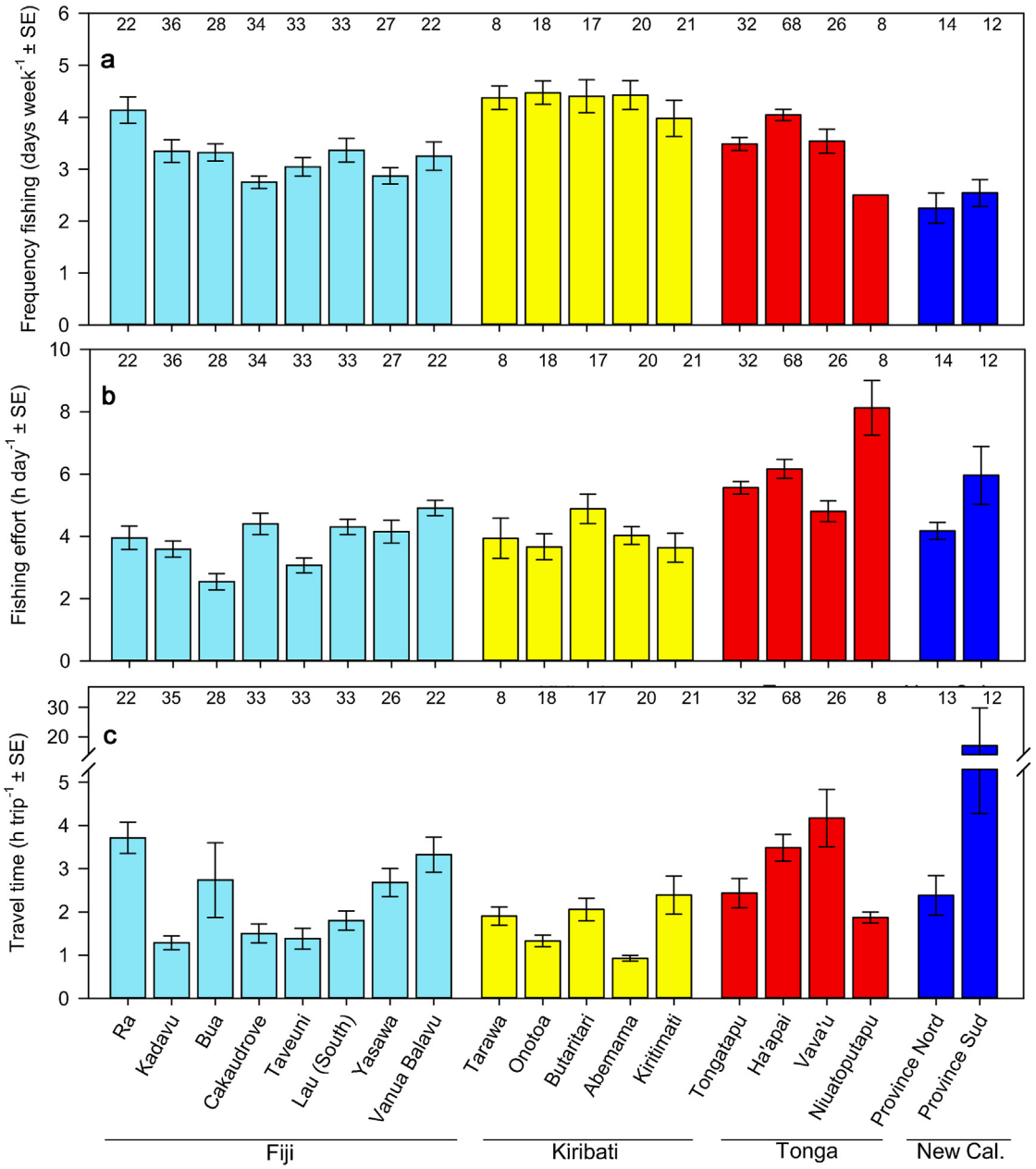

Fig. 3. Bar graphs across locations in each country for averages of (a) frequency of fishing, (b) fishing effort, and (c) round-trip travel time to get to and from fishing sites from their place of residence. Numbers at the top of each graph are sample sizes of respondents to those questions for each location below.

tational multivariate analysis of variance (PERMANOVA) to test for differences in the species caught by fishers among countries (fixed factor) and locations nested within countries (random factor). Non-metric multidimensional scaling (nMDS) was used to graphically ordinate the variations among countries and between genders.

3. Results

3.1. Gender, age and fishing history of fishers

Many women collected sea cucumbers, but the majority of interviewed fishers were men (Table 1). We interviewed few women in Kiribati, in part because of cultural taboos on interviews when their husbands were away working. In Kiribati, women apparently only glean and are a minor part of the fishery. Fishers included young adults and the elderly in each country, and the average ages of fishers were comparable, ranging 36–42 years.

The breadth of the fishing history of fishers varied among countries and greatly within countries (Table 1). On average, Fijian fishers were the most experienced and i-Kiribati fishers the least experienced. Experience in fishing sea cucumbers was only 3 years or fewer for 16, 54, 49 and 42% of respondents in Fiji, Kiribati, Tonga and New Caledonia, respectively.

3.2. Fishing methods and gears

Across all countries, the main fishing method was breath-hold diving (Table 2). These dive fishers travelled to fishing sites using sail and paddle-driven canoes or small boats that were usually 5–7 m long with 15–40 hp outboard engines. Breath-hold diving gear was sometimes very basic (Fig. 2c). A significant proportion of

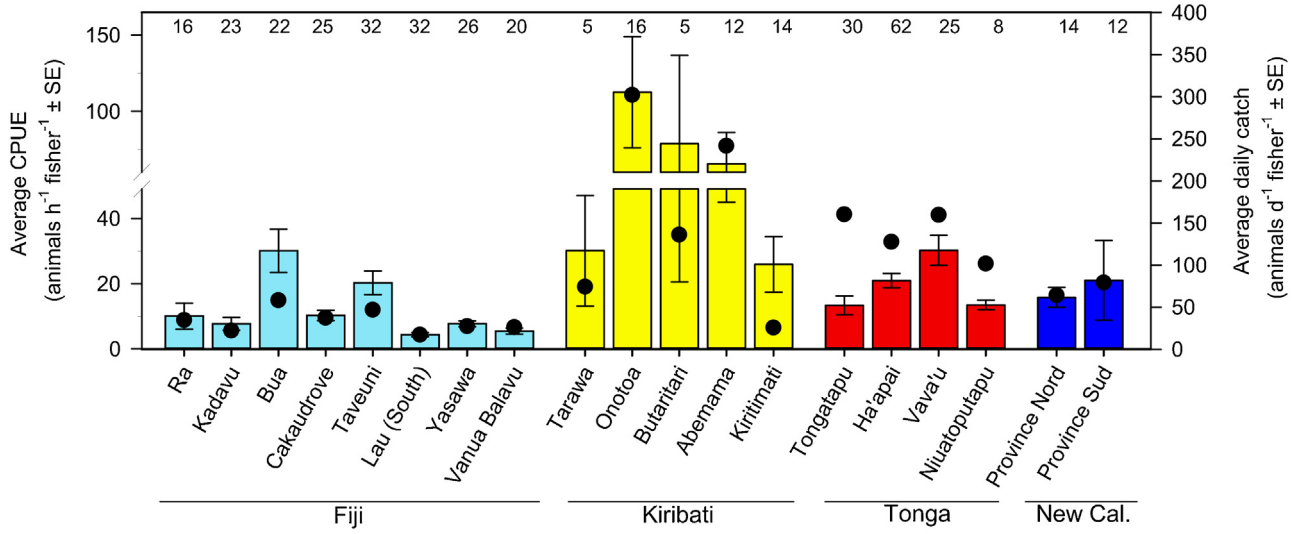

Fig. 4. Bar graph across locations in each country of average catch-per-unit-effort, expressed as the number of sea cucumbers caught per hour of fishing (bars, left-hand axis) and per day of fishing (dots, right-hand axis). Numbers at the top of each graph are sample sizes of respondents to those questions for each location below.

fishers also glean (wade in ankle to knee-deep waters) on reef flats to collect a variety of species, especially in Kiribati and New Caledonia (Fig. 2d). In each country, women gleaned more often than men, and men practised breath-hold diving more than women (Table 2). However, many of the Fijian and New Caledonian women practised breath-hold diving.

Compressed-air diving was relatively uncommon, and was rarely done by women. Fishers used SCUBA gear with tanks rather than 'hookah' gear using a boat-operated compressor. In Fiji, 18% of male fishers used SCUBA (Table 1). Some of those SCUBA fishers told of regularly fishing at 40–60 m depth. SCUBA equipment was commonly used from small boats, with an average of 4.2 divers per boat (Fig. 2e), but occasionally also from much larger boats.

Lead bombs, comprising a large weight with a barbed shaft (Fig. 2f), are lowered by rope by divers to access deep-water species, especially white teatfish *Holothuria fuscogilva*. This fishing gear was used almost exclusively by men (Table 2). Lead bombs were not used in New Caledonia, and used by around one-quarter of men in Kiribati and Fiji and more than half of the male fishers in Tonga.

3.3. Fishing effort and travel

The frequency at which fishers went fishing for sea cucumbers varied significantly among countries ($p < 0.01$), being much lower in New Caledonia (averaging 2.4 days week^{-1}) than the other countries (country averages: 3.2–4.3 days week^{-1}) (Supplementary material, Table S2) (Fig. 3). Fishing frequency also varied significantly among locations within countries ($p < 0.01$). On average, men went fishing more often than women ($p = 0.01$). Older fishers tended to go fishing significantly less often than younger fishers ($p < 0.01$). Years of experience fishing sea cucumbers did not have a significant bearing on the frequency of fishing trips ($p = 0.30$). Differences were non-significant for interaction terms.

Fishing effort varied greatly among countries ($p < 0.01$) (Supplementary material, Table S2) and was generally high. Average fishing effort was highest in Tonga (country: 5.9 h day^{-1}) and lowest in Fiji (country: 3.8 h day^{-1}), probably because some of the Fijian fishers used SCUBA gear that allows only short dives (Fig. 3). Fishing effort varied significantly among locations within countries ($p < 0.01$), and gender differences in fishing effort depended on locations (interaction: $p < 0.01$). Neither the age of fishers ($p = 0.13$) nor their years of fishing experience ($p = 0.40$) significantly influenced the hours spent fishing per trip.

Average travel times to get to and from fishing sites were comparable among countries ($p = 0.31$) and locations within countries ($p = 0.08$) (Supplementary material, Table S2). Substantial variation among fishers within locations is evident (Fig. 3). Women usually spent less time travelling to and from fishing sites, but differences were country-specific (country*gender interaction $p < 0.01$). Notably, women in Fiji had similar travel times to men, whereas women in New Caledonia and Tonga spent much less time travelling to sites than men, corresponding to a tendency to harvest on nearby fishing grounds. Travel times were neither significantly affected by fisher age ($p = 0.28$) nor their experience ($p = 0.94$). Multi-day fishing trips were practiced by 26% of fishers in Tonga and 27% of fishers in New Caledonia, but only by 2% of fishers in Fiji and by none in Kiribati.

3.4. Present catch rates

CPUE varied significantly among countries ($p < 0.01$) (Fig. 4) (Supplementary material, Table S2). Country-specific differences in CPUE between men and women were marginally significant (country*gender interaction: $p = 0.02$), and should be interpreted tentatively in view of analysis limitations. I-Kiribati fishers had the highest CPUE, averaging 65 ind h^{-1} (±15 S.E.), although it was variable geographically and attributed to some fishers collecting vast quantities of small low-value species, namely *Holothuria atra*. Tongan fishers also had high CPUE, averaging 24 ind h^{-1} (±2). Fijian fishers had the lowest CPUE, catching, on average, 12 ind h^{-1} (±1). CPUE differed significantly among locations within countries ($p < 0.01$). There was no significant effect of fisher age ($p = 0.55$) and years of experience fishing sea cucumbers ($p = 0.39$) on CPUE of fishers.

3.5. Catch composition

Species that fishers caught most frequently differed geographically and between genders (Fig. 5a). The PERMANOVA confirmed highly significant variations among countries (*Pseudo-F* = 6.24, $p = 0.001$) and locations within countries (*Pseudo-F* = 9.05, $p = 0.001$). A one-way ANOSIM test and the nMDS also showed

significant gendered differences ($R = 0.28$, $p < 0.001$) (Fig. 5b). The SIMPER test elaborated that the species typifying the catches of women were *Bohadschia vitiensis*, *H. atra, H. coluber and Stichopus chloronotus.* Across fisher groups, the SIMPER test and graphical illustration showed that species typifying captures of men and women in Fiji were *Actinopyga lecanora*, *B. vitiensis*, *B. argus*, *Holothuria atra*, and *S. chloronotus;* whereas in Kiribati were *A. mauritiana*, *H. atra* and *B. vitiensis*; and in Tonga were *A. lecanora, A. mauritiana, A. miliaris, B. argus and B. vitiensis* (Figs. 5b–d).

There were wide ranges of species harvested in each country and considerable variations among countries in the frequency at which fishers harvested each species (Fig. 5). Fiji had the widest range of species harvested. In addition to the 22 species in our survey questionnaire, we observed harvested *A. flammea*, *A. spinea*, *B. ocellata*, *H. coronopertusa*, and *S. monotuberculatus* at landing sites or processing stations. At least one species (*H. scabra*) occurring in Fiji does not occur in Tonga and seven are absent or harvested rarely in Kiribati (Fig. 5c). In some localities, fishers told they saw, but did not harvest, certain species because they were not accepted by buyers (e.g. *Pearsonothuria graeffei*, *H. fuscopunctata*).

3.6. Perceptions about stock status

At most locations, fishers believed, on average, that sea cucumber stocks are declining or depleted (Fig. 6a). On average, fishers in Taveuni, Fiji, believed stocks were presently stable, while fishers on Niuatoputapu in Tonga were the only ones to consistently believe that stocks were increasing. Commercial harvesting of sea cucumbers commenced in 2010 on Niuatoputapu, and fishers have on average only 2 years of experience fishing sea cucumbers, whereas other Tongan fishers had more experience (on average 6–9 years).

The most common reason cited for a decline in stocks was too many fishers exploiting the resources (Fig. 6b). Some fishers gave more than one reason. A change in fishing gear (e.g. recent use of SCUBA) to collect sea cucumbers was cited by some fishers in each country. Only in New Caledonia was pollution (e.g. from nickel mining) a common perception. Declines in stocks were attributed to natural causes (e.g. climate change) by 25% of fishers in Tonga, but by relatively few fishers in other countries.

3.7. Previous catches compared with current catches

The vast majority of fishers (82% across countries) believed they caught more sea cucumbers in the past. In many of the cases where fishers said they caught less in the past, they explained it was because they were previously targeting only a large high-value species, and caught few per day, or that they were relatively ineffective at fishing sea cucumbers when they first started.

The proportional difference between previous and current catches was highly variable in all four countries and variable over the years of fishing history (Fig. 7). This is because, when compared to present catches, some fishers recalled much higher fishing rates only a few years back while others recollect high fishing rates much longer ago. The modelled linear relationships across time were therefore weak in predicting the rate of decline in catches (r^2-values: 0.01–0.18). For fishers with ten or more years of experience, the average proportional difference in CPUE between when they first started fishing and the year preceding the interview was 2.0 (±0.9 s.e.) for Tongan fishers, 1.5 (±0.2 s.e.) for i-Kiribati fishers, 11.8 (±4.2 s.e.) for New Caledonian fishers, and 3.5 (±0.5 s.e.) for Fijian fishers. Viewed another way, those experienced fishers claimed that CPUE is 50% lower in Tonga, 33% lower in Kiribati, 72% lower in Fiji and 92% lower in New Caledonia nowadays when compared to catches 10 or more years in the past.

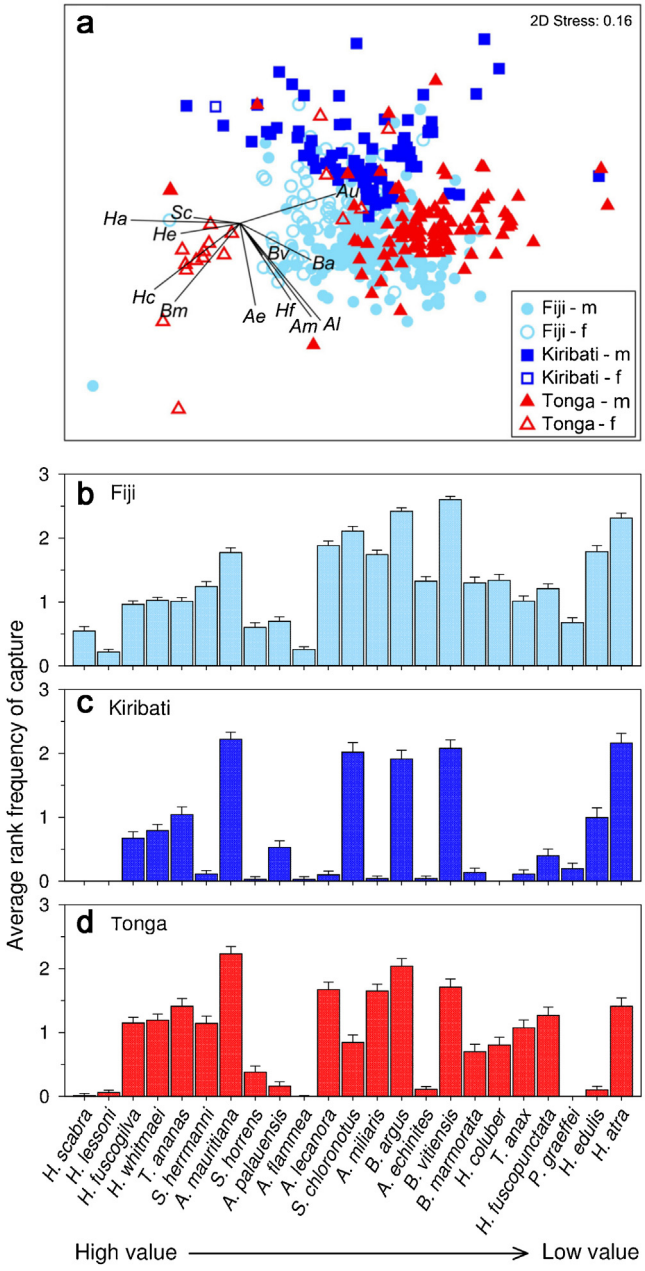

Fig. 5. a) nMDS ordination of the rank frequency (0–3) of capture of 23 species of sea cucumbers among Fiji, Kiribati and Tonga. Open symbols are women, closed symbols are men. Vectors are Pearson correlations for 12 species shown in the SIMPER analysis to be most important in depicting catches for each country. Species: Ae = *Actinopyga echinites*, Al = *A. lecanora*, Am = *A. miliaris*, Au = *A. mauritiana*, Ba = *Bohadschia argus*, Bm = *B. marmorata*, Bv = *B. vitiensis*, Ha = *Holothuria atra*, Hc = *H. coluber*, He = *H. edulis*, Hf = *H. fuscopunctata*, Sc = *Stichopus chloronotus*. b-d) Bar graphs of average perceived frequency of catching each species across Fiji, Kiribati and Tonga; 3 = often, 2 = sometimes, 1 = rarely, 0 = never. New Caledonia not included. Species are in decreasing order of maximum market value from left to right based on Purcell (2014).

4. Discussion

4.1. Fisher types and experience

Across fisheries globally, women account for more than 15% of people directly engaged in fisheries (FAO, 2014). Sea cucumber fisheries in the Indian Ocean and southeast Asia are often dominated by men (Choo, 2008; Eriksson et al., 2015a; Muthiga and Conand,

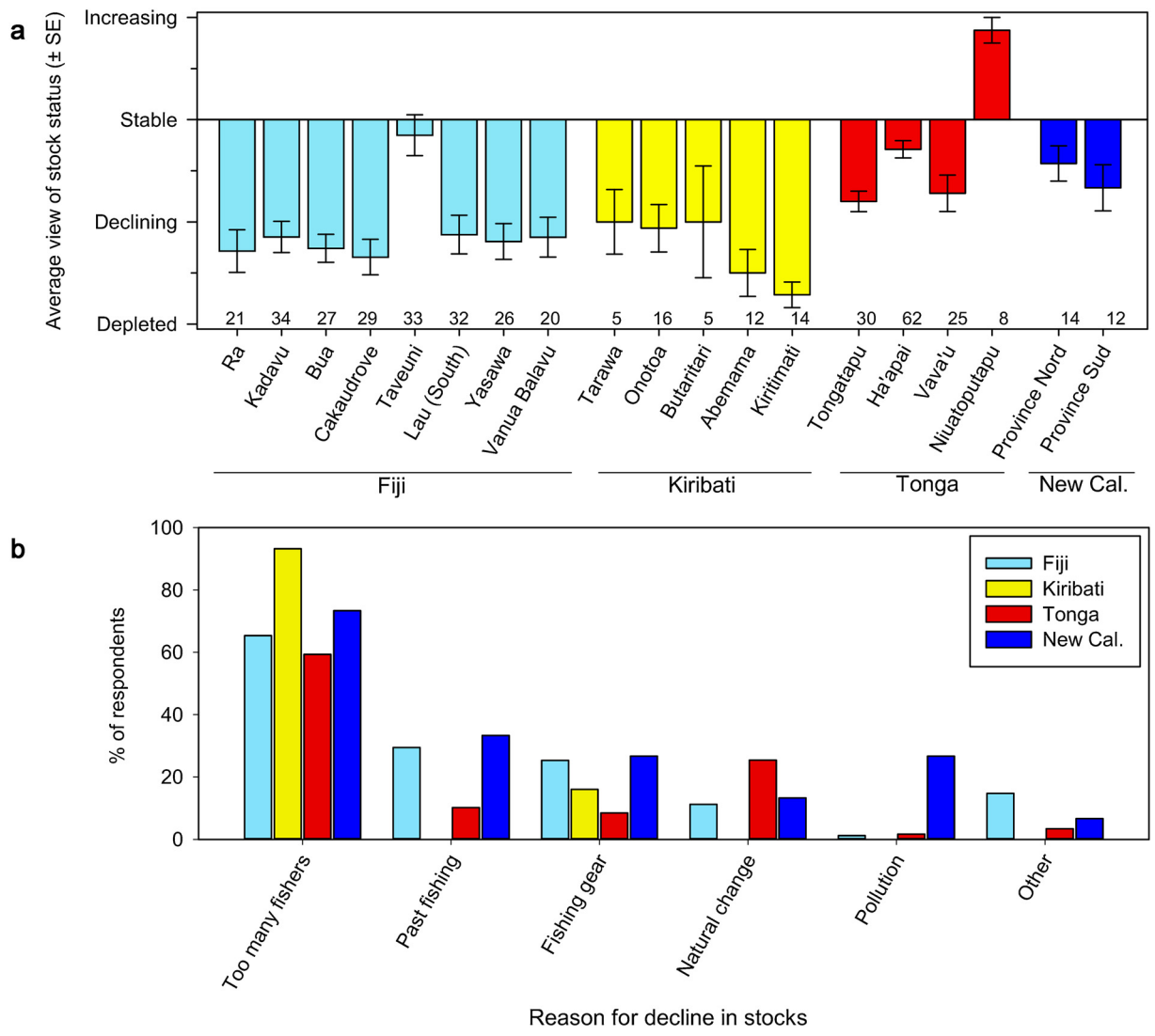

Fig. 6. a) Fishers' views about the current status of sea cucumber stocks in study locations within each country. Responses were scored as: increasing = 1; stable = 0; declining = −1; depleted = −2. Replication (n) of fishers who responded to the question in each location is given along the x-axis. b) Perceived reasons for declines in stocks among the four countries. Bars are percentages of respondents out of fishers who believed stocks were declining or depleted.

2014; Ochiewo et al., 2010). Our study suggests that women can play an important role in Pacific Island sea cucumber fisheries.

Sea cucumber fishing is clearly a livelihood activity that engages adults of all ages, and we heard of children helping to collect sea cucumbers on school holidays. Similarly in Madagascar, all family members collect sea cucumbers (Muthiga and Conand, 2014). Our results from Oceania concur with those in Philippines that young fishers fished more frequently than older fishers (Muallil et al., 2013). Surprisingly, age did not affect catch rates, inferring that fishers remain efficient harvesters into their middle and senior years.

Sea cucumber fishing was not, generally, a longstanding occupation for fishers except in Fiji. Roughly half of the fishers in Kiribati, Tonga and New Caledonia, would have little grounds to claim that fishing and selling sea cucumbers has long been one of their livelihood activities. Variations in fishers' experience can be partly attributed to the history of the fisheries. For example, fishing experience averaged 7 y in Tonga, where a recent 10-year moratorium (Pakoa and Bertram, 2013) would have prevented some young fishers from entering the fishery until recently. However, average fishing experience was also relatively short among i-Kiribati fishers despite that fishery being opened for many years. For many Pacific Islands, fishing of sea cucumbers dates back 150–200 years (Conand, 1990; Kinch et al., 2008b), so although their own involvement in the fishery might be recent, new fishers could still justifiably claim that it is a traditional livelihood of their past generations. These issues are relevant to any move towards 'limited entry' regulations as a potential management measure to limit overall harvests in these fisheries (Purcell, 2010; Purcell et al., 2014a). Claims of longstanding involvement in the fisheries (e.g. in Fiji), in addition to dependency and the role of sea cucumber fishing in alternatives-limited livelihoods, will need to be taken into account when considering limited-entry regulations as a new management measure. Alternatively, short fishing seasons could be applied and adapted in light of fishery performance (Léopold et al., 2013; Purcell and Pomeroy, 2015).

4.2. Fishing methods

As found in countries throughout southeast Asian (Choo, 2008) and the Indian Ocean (Muthiga and Conand, 2014), sea cucumber fishing gears vary from area to area, ranging from mask only to modern diving equipment. Breath-hold diving gears are often used in fishing of other reef resources, such as octopus, lobster and fin-

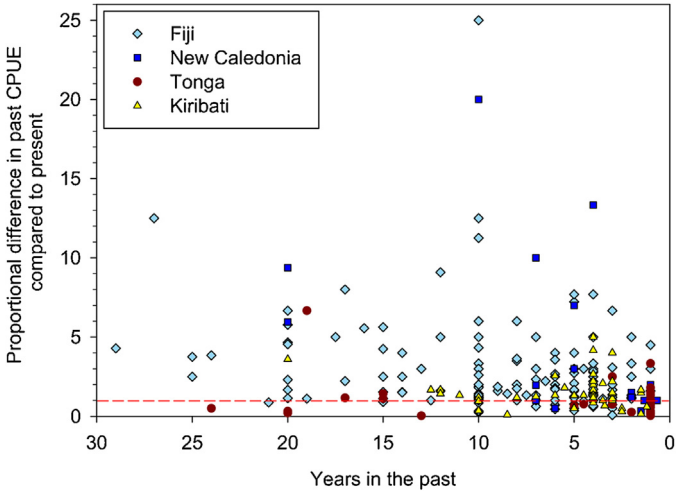

Fig. 7. Scatter plot of perceived historical CPUE (pieces day^{-1}) compared to present CPUE. Dashed red line distinguishes cases in which respondents claim that catches per day were higher (above) or lower (below) in the past compared to present catches. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

fish, which may be encountered while searching for sea cucumbers. Women are often stereotyped as gleaning sea cucumbers while men dive (Choo, 2008; Eriksson et al., 2010; Kinch et al., 2008b; Raboanaijoana, 2013). Women did glean more often than men, but our study shows that a lot of men also practice gleaning, and a significant proportion of women fishers use breath-hold diving in certain fisheries. Gender-inclusive development and communication of fishery management measures in these fisheries thus must consider women as not strictly gleaners or insignificant to fishery production.

The frequency at which gleaning, breath-hold diving, and compressed-air diving, are used in hand-collectable fisheries such as those studied here can be a reasonable indicator of stock status (see Friedman et al., 2008). Fishers tend to start by gleaning stocks in nearby shallow waters, then move to breath- hold diving and eventually to compressed-air diving as shallow populations are depleted (Eriksson et al., 2015b; Friedman et al., 2011). There are reasons why this is not strictly the case. Nonetheless, the higher incidence of SCUBA diving in Fiji and the low frequency of gleaning in Tonga corroborates recent reports that these two fisheries are over-exploited (Pakoa et al., 2013a,b). There are reports that the provision of exemptions for authorised villages to use SCUBA equipment in Fiji will soon be repealed, and our data from fisher perceptions indicate that many fishers would welcome this change in the context of reducing fishing pressure. Such ratios of gleaners:breath-hold divers:compressed-air divers might even be more informative for diagnosing or monitoring fisheries than CPUE, which in multi-species fisheries are so influenced by harvest strategy and can be misleading.

Lead bombs are prohibited in some fisheries through a regulation of collection by hand only, to limit over-exploitation of deep-water stocks and prevent damage to the animals which affects export quality (e.g. Skewes et al., 2010). The common usage of lead bomb in Tonga is indicative of over-exploitation of shallow-water stocks. In contrast, fishers in New Caledonia were not using lead bombs at the time of survey, even though these were not prohibited in the provincial fisheries (Purcell et al., 2009). Our data indicate that any reforms in Tonga, Kiribati and Fiji to prohibit these fishing gears should involve communication of regulations, especially with male fishers, and inspections at sea.

4.3. Time investments

Sea cucumber fishing was a full-time occupation in some countries and locations. For example, i-Kiribati fishers went fishing on average 4–4.5 days each week at most locations and spent 3.6–4.9 h in the water searching for sea cucumbers, leaving few days to devote to other things such as family, household duties, religion and rest. The slightly lower average fishing frequencies in Fiji and Tonga (2.5–4.1 days week^{-1}) could be explained by time investment in gardening, which is not practised much in Kiribati due, in part, to poor soils and culture (Thomas, 2002). Disparities in fisher income per fishing trip (Purcell et al., unpubl. data) could also be an underlying cause of these inter-country differences. The average fishing frequencies in Kiribati, Tonga and Fiji are comparable to Filipino small-scale fishers (means: 3.5–4.6 days week^{-1}) (Muallil et al., 2013) but higher than reported in Solomon Islands (Ramofafia et al., 2005) and Papua New Guinea (Kaly et al., 2005) and Kenya (Ochiewo et al., 2010). Lower fishing frequencies in New Caledonia indicate that fishers there might have earned relatively more from other income streams than in the other three countries or that sale prices could have been higher such that they earn sufficient money from 2.5 days per week of fishing sea cucumbers, although market forces between survey dates may have influenced this comparison. Our findings infer that any future reforms to impose short fishing seasons as a means to reduce overall fishing pressure in these fisheries might only marginally increase current frequency of fishing trips per week for existing fishers in many locations in Fiji, Kiribati and Tonga because fishers would only be able to increase their frequency by one or two days per week during short seasons. By comparison, many fishers in New Caledonia appear to have the capacity to double their fishing frequency per week in response to potential imposition of short fishing seasons.

Fishing effort, in terms of hours spent in the water per day, in most locations was comparable to that of fishers in some other tropical fisheries in the Indo-Pacific (Eriksson et al., 2012; Kaly et al., 2005; Ochiewo et al., 2010). Fishing effort in Tonga (average: 5.9 h day^{-1}) was high compared to Fiji (average: 3.8 h day^{-1}), perhaps because Tongan fishers sometimes camped on nearby islands or slept on the boat on over-night trips and could spend more time each day in the water fishing.

Table 2
Fishing methods used among the study countries.

Location	Gender	Frequency of method used (%)			
		Gleaning in shallow waters	Breath-hold diving	SCUBA	Lead bomb
Kiribati	F	100	0	0	0
	M	70	95	7	24
Tonga	F	100	3	0	0
	M	31	98	4	58
Fiji	F	84	87	3	3
	M	31	94	18	23
New Caledonia	F	100	75	0	0
	M	64	82	0	0

Large location-specific variations in travel times to fishing sites may reflect geographic variations in stock abundance and proximity to fishing grounds (see Pakoa et al., 2013a,b; Purcell et al., 2009). Interestingly, although women gleaned more than men in Fiji, their similar travel times to men infers that gleaning may not always be nearby and can demand high investment of time. Long travel times, as experienced by some fishers in Tonga and New Caledonia to reach distant reefs with large boats, should raise concern for resource management. A potential measure would be capacity limitations on boat length (Purcell, 2010; Purcell et al., 2009), to reduce the potential for sea cucumber fisheries to expand to more industrialised forms of fishing with large teams of divers making multi-day trips (Friedman et al., 2008).

4.4. Present catch rates

Recent reports show large variation in abundances of sea cucumbers among locations in Fiji and Tonga (Pakoa et al., 2013a,b), which partially explains the variable CPUE among locations in our study. Seasonal differences in sampling dates among locations could also affect CPUE. Differing fishing strategies could also help explain variations among locations, whereby fishers on some islands were collecting large numbers of low-value species. Low CPUE in some locations in Fiji can be partly attributed to fishing strategies, whereby SCUBA divers target large or high-value species but collect few of them compared to breath-hold divers or gleaners in shallow waters. Comparisons of CPUE over time or among fisheries can thus be confounded by differences in fishing strategies.

Catch rates per day by fishers are actually comparable to catch rates per boat (with teams of divers) in Sri Lanka (Dissanayake and Stefansson, 2012), indicating that CPUE rates per fisher were nonetheless greater in Oceania. However, CPUE across Fijian sites in our study (11.6 pieces h^{-1}) was 28% lower than a previous report by Dalzell and co-authors for Fiji (Dalzell et al., 1996). CPUE per day in most of our study locations was also much lower than for divers fishing *Holothuria mexicana* and *Astichopus multifidus* in Puerto Rico (175–300 sea cucumbers $fisher^{-1}$ day^{-1}) (Miguel et al., 2013), which is a recently developed fishery (Eriksson et al., 2015c).

4.5. Catch composition

Catch composition differed most between Kiribati and Tonga, which are furthest apart geographically and are at the eastern distributional limits of several commercially-exploited species (Purcell et al., 2012). The high diversity of harvested species (27+) in Fiji is similar to that in Papua New Guinea and Solomon Islands when those fisheries operated (Kinch et al., 2008a; Ramofafia et al., 2005), and higher than in most other Pacific Island nations (Kinch et al., 2008b). The slightly less diverse catches in Tonga and much less diverse catches in Kiribati can be attributed in part to distributional ranges of species but also somewhat to buyer preferences.

Significant disparities in catch composition between men and women fishers can be attributed to fishing methods. Species shown to be more often collected by women are typical of shallow habitats (Purcell et al., 2012). Those shallow-water species are generally of lower economic value than species in deep waters, more often fished by men (see Purcell, 2014), so one may expect catches to yield less income for women. SCUBA divers catch very different species (e.g. *A. palauensis*, *B. ocellata*, *H. coronopertusa*, *H. fuscogilva*, *T. anax*) than gleaners and somewhat different to breath-hold divers. The SCUBA divers were predominantly men, so the catches of those divers also contributed to the overall gender differences in catch composition.

Gender variation in catch composition should be considered for certain capacity-building programs and regulatory measures. For instance, workshop and information tools to improve post-harvest processing by fishers (see Purcell et al., 2016) should demonstrate methods for species harvested by both men and women. Shortlists of allowable species have been proposed as a useful new measure for sea cucumber fisheries (Branch et al., 2013; Purcell et al., 2014a, 2013) and we are aware that these are now components of new management arrangements for Fiji and Kiribati. Our analyses highlight an additional caveat for these regulations—shortlists should include some species commonly fished by women or risk marginalising them through such management reforms.

4.6. Perceptions about stock status and long-term trends in CPUE

Belief by a majority of fishers that stock have been declining, or are depleted, is a strong indicator of over-exploitation (Friedman et al., 2008). Stock declines have also been indicated through perceptions of fishers and traders in Zanzibar (Eriksson et al., 2010). Underwater visual census is a prevalent tool to assess sea cucumber populations but is costly and requires technical diving skills. In contrast, socioeconomic surveys draw on fisher knowledge and are relatively inexpensive.

Across sea cucumber fisheries globally, high participation rates are strongly related to per-capita catch rates and overall fishery sustainability (Purcell et al., 2013). This study shows that fishers agree that the "accelerator" in small-scale fisheries (Purcell and Pomeroy, 2015) is a fundamental issue to address. Too many fishers was the most commonly cited reason for perceived declines in stock abundance, indicating that participation rates are too high in these sea cucumber fisheries. The relatively high proportion of new entrants in the fisheries, except in Fiji, should be a case in point for resource managers to consider limited-entry regulations (i.e. via licence).

Fisher knowledge can be valuable for revealing long-term trends in catches (Bender et al., 2014), although caution is needed owing to potential bias in fisher perceptions (Daw et al., 2011; O'Donnell et al., 2012) and variability in the magnitude of difference in past catches with years of experience of fishers. In the present study, most fishers reported higher catch rates in the past, and knowledge from the most experienced fishers suggested that recent catches were 33–92% lower than catches 10 or more years ago. These findings suggest that stocks in all countries have been heavily exploited in recent decades.

4.7. Limitations of the study

Surveys in New Caledonia were done four years before those in Tonga and Kiribati, and surveys in Fiji were done three years later. We were therefore tentative about inter-country comparisons, especially between New Caledonia and Fiji. Potential biases could arise from the lag in time between surveys in the different countries because the fisheries were not under identical market forces at the time of the surveys. Market demands and export prices have soared over recent decades (Purcell, 2014) and might have, for example, spurred more intensive exploitation in recent years in Fiji than 7 years prior in New Caledonia. Biases are likely for comparisons of prices, but those data are not presented in this study, and less problematic for comparisons of data on fishing modes, catch composition and perceptions. Each country has their own independent history of fishing sea cucumbers and management regimes and stocks are not shared (Kinch et al., 2008b).

We also acknowledge that our sampling of fishers was not random. Our sampling was intentionally gender-inclusive by seeking to interview women where possible, so the proportions of men and women that we interviewed should not be used to gauge gender participation in the fisheries. Additionally, sampling at different times of the year in different locations was an inherent limitation, and should be considered when comparing catch rates and effort

since, for example, fishers could spend more time fishing in summer than winter.

Finally, we also stress that our data on CPUE are based on fishers' perceptions. Catches reported by fishers in other small-scale fisheries can be inflated compared to actual landings (Daw et al., 2011). We did not collect matching data on landings, except for in New Caledonia, where there did appear to be region-specific bias in CPUE perceived by fishers compared to actual landing data (Purcell et al., 2009).

5. Conclusions

This study underscores that sea cucumbers offer a valuable case for examining small-scale artisanal fisheries because they are multi-species, involve men and women of varying ages and different fishing methods and gears. High fishing effort, catches of low-value species and predominant perceptions by fishers that stocks have significantly declined are indicators that these resources are under unsustainable pressure (Muthiga and Conand, 2014). Our questionnaire-based socioeconomic surveys revealed much about user groups, species abundances, historical comparisons with current catches, and key management needs for the fisheries. Researchers and development agencies, and fishery management institutions, agencies should better exploit these fishery-dependent tools for fishery diagnosis and monitoring.

Resource managers must adopt new approaches to manage small-scale fisheries, such as those mentioned here. Our findings and appraisal point to the use of short fishing seasons and gender-sensitive shortlists of allowable species as suitable new measures. Gear restrictions on the use of lead bombs and compressed-air diving should be accompanied by investment in enforcement at sea and communication programs, directed especially towards men. Restricting fishing will unlikely be easily accepted by fishers, many of whom harvest sea cucumbers on most weekdays. Transformations towards fishery sustainability will need to better understand fishers and their exploitation of marine resources.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.fishres.2016.05.010.

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