frontiers in Marine Science

ORIGINAL RESEARCH
published: 22 February 2018
doi: 10.3389/fmars.2018.00052

Conservation Concerns of Small-Scale Fisheries: By-Catch Impacts of a Shrimp and Finfish Fishery in a Sri Lankan Lagoon

Benjamin L. Jones[1,2]*, *Richard K. F. Unsworth*[2,3], *Susantha Udagedara*[4] and *Leanne C. Cullen-Unsworth*[1,2]

[1] Sustainable Places Research Institute, Cardiff University, Cardiff, United Kingdom, [2] Project Seagrass, Sustainable Places Research Institute, Cardiff University, Cardiff, United Kingdom, [3] Seagrass Ecosystems Research Group, College of Science, Swansea University, Swansea, United Kingdom, [4] Blue Resources Trust, Colombo, Sri Lanka

OPEN ACCESS

Edited by:
Rodrigo Riera,
Atlantic Environmental Marine Center (CIMA SL), Spain

Reviewed by:
Dyhia Belhabib,
University of British Columbia, Canada
Konstantinos Tsagarakis,
Hellenic Centre for Marine Research, Greece
Dimitrios K. Moutopoulos,
Technological Educational Institute of Messolonghi, Greece

***Correspondence:**
Benjamin L. Jones
jonesB67@cardiff.ac.uk

Specialty section:
This article was submitted to Marine Fisheries, Aquaculture and Living Resources, a section of the journal Frontiers in Marine Science

Received: 22 September 2017
Accepted: 02 February 2018
Published: 22 February 2018

Citation:
Jones BL, Unsworth RKF, Udagedara S and Cullen-Unsworth LC (2018) Conservation Concerns of Small-Scale Fisheries: By-Catch Impacts of a Shrimp and Finfish Fishery in a Sri Lankan Lagoon. Front. Mar. Sci. 5:52. doi: 10.3389/fmars.2018.00052

By-catch is considered a significant problem in large-scale fisheries yet in small-scale fisheries (SSF), employing >99% of the world's fishers, there is limited quantitative understanding of by-catch, and catches in general. We provide an assessment of by-catch from fishing gears (fyke, trawl, set trammel, and drift trammel nets) commonly used in small-scale fisheries across the globe, using a representative Sri Lankan case study and placing this in the context of local resource use patterns. We reveal evidence of how SSF generate significant finfish by-catch with potentially significant ecological impacts. Fishers targeting shrimp (fyke, trawl, and drift trammel nets) caught more non-target species than global averages (44, 44, and 67% by weight, respectively). Fishers targeting finfish (set trammel nets) caught fewer non-target species. We found that by-catch depends more on target species and gear type, supporting suggestions that SSF are not "inherently more sustainable" than their large-scale counterparts and a collective effort is required for an improved understanding of the impacts of SSF. This study highlights an additional issue of valuable food fish discards, raising questions about fisheries exploitation in the context of food security in areas where poverty and food insecurity are prevalent.

Keywords: by-catch, discards, non-target species, shrimp fisheries, small-scale fisheries, Sri Lanka

INTRODUCTION

Man's impact on ocean diversity change is understood mainly through limited snapshots or subsamples of diversity, like charismatic organisms, commercially-important fisheries, or coral reef ecosystems (Carpenter et al., 2008; Collette et al., 2011; McClenachan et al., 2012; Ricard et al., 2012; Pauly and Zeller, 2016). The same applies to the impacts of the words fishing gear, where the majority of what we know comes from studies of large-scale fisheries, where overexploitation, bycatch, and habitat destruction are commonly encountered and well-documented (Dayton et al., 1995; Hutchings, 2000; Dulvy et al., 2003; Kappel, 2005; Lotze et al., 2006; Polidoro et al., 2012; Zeller et al., 2017). Globally, at least 7.3 million tones (t) of fish (usually dead or dying) are thought to be discarded from marine fisheries annually (Kelleher, 2005; Zeller and Pauly, 2005). Similarly, by-catch forms on average 40.4% of catch (Davies et al., 2009). Discard estimates come mostly from observations of major or large-scale industrial fisheries (Zeller et al., 2017). In comparison, limited attention has been paid to small-scale fisheries (SSF) (Fennessy and Everett, 2015; Temple et al., 2017) which are assumed to have low discard rates, for example around 3.7% total catch (Kelleher, 2005).

SSF likely account for more than half of total global fisheries production and employ more than 99% of the worlds 51 million fishers (Berkes et al., 2001; Peckham et al., 2007; Teh and Sumaila, 2013). While there is increasing recognition of the need for improved management of these fisheries, there remains limited context-specific understanding of their social-ecological complexity, particularly concerning discards and by-catch. Discards are categorized as fish and other marine life that are thrown overboard, whereas by-catch are fish and other marine organisms that are caught but not targeted (Zeller et al., 2017). However, by-catch may or may not be discarded (Zeller et al., 2017) making defining the terms difficult. Given that there is increasing recognition that SSF are "too big to ignore" (Chuenpagdee, 2011; Jentoft and Chuenpagdee, 2015; Pauly and Zeller, 2016; Too-Big-to-Ignore, 2017) there exists an urgent need to characterize SSF catch in terms of non-target catch and discards. Previous studies have addressed the impacts that SSF have on charismatic species. These include seabirds (Croxall et al., 2012; Lewison et al., 2012, 2014), marine turtles (Koch et al., 2006; Wallace et al., 2011), marine mammals (Omar et al., 2002; Lopez et al., 2003; Read et al., 2006; Kiszka et al., 2008), and sharks (Dulvy et al., 2008; Ferretti et al., 2010). However, there remains limited information with significant disparities in available data on the impact of SSF on non-target fish species (Shester and Micheli, 2011; Zimmerhackel et al., 2015). Part of the problem is that SSF are site and context specific and generally difficult to define. Therefore, detailed case studies or snapshots are required to determine the potential impacts of these fisheries and their role in realizing sustainable development goals.

Lagoon systems provide a suitable setting to understand complex SSF as they are generally human-dominated and their resources used intensively. With geographical boundaries, the impacts of humans can often be considered a key part of lagoon ecology (Berkes and Seixas, 2005). Within semi-tropical developing countries, small-scale and artisanal fisheries are fundamental components of lagoons but characteristically suffer from a "tragedy of the commons" (Kalikoski et al., 2002). Lagoonal SSF in developing countries are generally remote and beyond the reach of central governments. However, this doesn't always reflect a lack of governance (Stevens et al., 2015), where strong social networks and a sense of community ensures that resource use is managed effectively by resource users. Due to this, gear types are generally similar in lagoon systems and globally, fishers operating in lagoons routinely use stake nets, fish fences or variations of fyke nets, where the primary resource tends to be either shrimp or finfish (Mathew, 1991; Amarasinghe et al., 1997; Panini, 2001; Kalikoski et al., 2002; Seixas and Berkes, 2003; Lobe and Berkes, 2004). Seine nets, gill nets, and trawls are also common in lagoon systems across the globe targeting finfish from the Mugilidae and Ariidae families (Kalikoski et al., 2002; Seixas and Berkes, 2003).

There is a growing realization of the significant contribution that SSF play in global fisheries catch and the associated implications of these fisheries for the sustainability of our oceans and their role in realizing Sustainable Development goals. Given this, we sought to quantify and compare for the first time the potential impacts of four artisanal fishing gear types (fyke, trawl, set trammel, and drift trammel nets) from a small-scale Sri Lankan lagoon fishery regarding their by-catch. We investigate the impact of gear type and target species on by-catch and discuss some of the context-specific socio-economic factors driving resource use and fishing preference in these types of system, and use this case study as a representative lagoonal fishery to highlight the magnitude of associated SSF by-catch more broadly.

METHODS

Study Location and Background Information

In Sri Lanka lagoonal small-scale fisheries (SSF) are particularly abundant, with over 100 lagoons along its 1,340 km coastline (Silva et al., 2013). These fisheries support the livelihoods of 2% of Sri Lanka's population (some 500,000 people; Samarakoon and Samarawickrama, 2012), providing up to 40% of livelihoods in some locations (Ranasinghe, 2010). Sri Lankan lagoonal fisheries saw a near tripling in its fisher numbers between 1986 and 2011 along with a general move from subsistence to a commercial enterprise (IUCN, 2012). Associated income is estimated to be more than five billion rupees (39.6 million USD; Samarakoon and Samarawickrama, 2012), with shrimp exports alone valued at nearly three billion rupees (19.5 million USD; MFARD, 2015).

This study was conducted in Puttalam lagoon (**Figure 1**), in the Puttalam district on the north-western coast of Sri Lanka (IUCN, 2012). When joined with Dutch Bay and Portugal Bay, the lagoon forms Sri Lanka's most considerable brackish water body (IUCN, 2003b) covering an area of 46,000 ha characterized by open water, mudflats, mangroves, seagrass, and salt marsh (IUCN, 2003a; Ranasinghe, 2010).

The Puttalam district contains 16 Divisional Secretariat Divisions (DSD's), where DSD's are administrative sub-units governed by a "divisional secretary" (Department of Census Statistics, 2011). There are 4 DSD's around the lagoon, Puttalam, Kalpitiya, Mundel, and Wanathavilluwa, but only populations in Puttalam, Kalpitiya, and Wanathavilluwa depend directly on the lagoon for food and livelihoods (Ranasinghe, 2010).

Over 15,000 fishermen target the lagoon, 90% of whom depend on fishing as their sole source of income (IUCN, 2012). The southwest monsoon sees an additional influx of fishers from coastal reef fisheries, which are too rough to be fished from June to September (IUCN, 2012), these fishers tend to operate larger boats targeting different species to fishers who operate in the lagoon all year round. The most common gear types used within the lagoon are variations of trammel nets (set and drift) which are used to catch finfish (74%) and shellfish (crustaceans) (26%), however, professional fishers also use illegal gear such as fyke nets and trawl nets. While trawls are generally not considered SSF,

FIGURE 1 | Location of the landing site in Kalpitiya North and fishmongers (*Wardi*, Kalpitiya North; *Razeek*, Kalpitiya center) used in present study along with interview regions within Puttalam Lagoon (Sri Lanka).

within the Puttalam Lagoon these are small and assisted not by motor but by wind and operated from traditional craft with sails.

Catch Survey

A scoping exercise was conducted around the lagoon to identify a representative landing site. A total of 42 landing sites were identified (generally 1 for every 1 km of lagoon coast). The majority of landing sites were utilized by seagrass fishers operating non-motorized traditional craft (NTRB), given that seagrass fringes the coasts of the lagoon. Only a small number, closest to Puttalam town, were characteristically different—made up of much larger boats suitable for fishing outside of the lagoon. The catch survey was conducted at the landing site of a multi-gear seagrass associated fishery in Kalpitya North (**Figure 1**) being characteristic of the majority of fishing communities around Puttalam Lagoon.

The entire catch from 63 distinct fishing trips was recorded at the point of landing over 7 days in August 2015. Catch composition was recorded to species level together with the size of the first 20 individuals of each species as they were removed from fishing gear. For trammel and trawl nets, all fishers brought nets ashore to remove catch. Similarly, fishers using fyke nets placed all of the catch into a crate and brought it to shore before sorting. Gear type, mesh size, hours spent fishing, preferred fishing habitat, transport type, target species, and total catch weight were also recorded. Species that were discarded, and thus deemed by-catch, were recorded as fishers removed them from their nets. The authors were present for two trips to retrieve catches and confirmed that no sorting of the catch occurred at sea due to (1) time and (2) size of craft. Species were grouped into three categories, 1 = always discarded, 2 = discarded if small, and 3 = always kept (Appendix A in Supplementary Material). To determine the juvenile composition of the catch, size at maturity data was collated from the literature. Where length at maturity data was not available (Froese and Pauly, 2016) it was defined by one-third of the maximum length of each species (Harmelin-Vivien et al., 1985).

Market Survey

Over the same period as the landing survey, a survey was conducted at two local fishmongers (Wardi, Kalpitiya North and Razeek, Kalpitiya Centre). Wardi was the only fishmonger near the landing site at Kalpitiya North, and all fishers operating at this site would sell here. Market owners were additionally asked to record which species customers requested on each day as well as the total weight of each species sold per day.

Interviews

Two hundred household surveys were carried out across the 3 DSD's that surround Puttalam Lagoon (August–September 2015; Unsworth and Cullen, 2010; **Table 1**). Households were randomly selected, and respondents were given project information before asking for consent to take part. Verbal consent was obtained. Respondents were interviewed to ascertain information on fishing characteristics (if fishers) and household fish consumption.

Respondents provided their preferred five choices of fish and invertebrates for consumption. If the respondents classified themselves as fishermen (either part time or full time), they were asked how they disposed of by-catch. Due to multiple language uses around the lagoon (notably Sinhala and Tamil), not all fish names could be translated into Latin at the species

TABLE 1 | Number of respondents interviewed across 3 Divisional Secretariat Divisions (DSD's) surrounding Puttalam Lagoon along with the number of lagoon landing sites in each DSD.

DSD	Number of respondents interviewed	Number of lagoonal landing sites in DSD
Kalpitiya	127	27
Puttalam	38	6
Wanathawilluwa	35	8

level. Although some individuals were identified to species level (following the landing survey), others corresponded to family or order.

Data Analysis

Differences in the total number of species caught, the magnitude of by-catch and the number of target species caught across gear types were analyzed using SPSS v. 23. Data were tested for normality using a Shapiro–Wilk test. Where data were not normally distributed, transformations were attempted. Where transformations were not possible, non-parametric tests were used. One Way ANOVA was used to test for differences in the number of species caught and the prevalence of by-catch across gear types and Kruskal–Wallis used to test for differences in target species caught across gear types (Underwood, 1997). A T-test was performed to investigate differences in catch composition and magnitude of by-catch (number of non-target species caught) between target type (classified as finfish or shrimp) and a Mann–Whitney U was used to test for differences in the number of target species caught between target types (finfish and shrimp; Stewart et al., 2010). Additionally, a Kruskal–Wallis test was used to test for differences in life stage of by-catch (adult or juvenile) across gear types and a Mann–Whitney U-test was used to test for differences in life stages of by-catch (adult and juvenile) between target type (finfish and shrimp).

Analysis of the differences between fish species assemblages across gear types and between target types was carried out using Primer v6 (Clarke and Gorley, 2006). Multi-dimensional scaling (MDS) plots were generated with superimposed Bray Curtis similarity clusters at the 40% similarity level. ANOSIM (analysis of similarities) and pairwise tests were used to test the similarity between a priori defined groups of samples (i.e., gear type). SIMPER analysis (Similarity Percentages) was carried out to test for species contributions to the Bray Curtis similarity between and within a priori defined groups (Clarke, 1993).

RESULTS

Target Catch, Gear Use, and Preferred Habitat

Shrimp (*Penaeus* spp.) was the target for over 80% of the fishing trips observed. Shrimp fishers used a combination of gear types both legal (trammel net) and illegal (trawl net, fyke net; **Table 2**). All fishers used non-motorized traditional craft (NTRB) and trawls were assisted using wind power. Fishers using set trammel nets for finfish were only targeting Mullet (*Mugilidae* spp.), rabbitfish (*Siganus* spp.), and the green chromide (*Etroplus suratensis*).

All fishers at the landing site preferred fishing on seagrass over any other habitats and every fishing trip observed was within shallow seagrass (1–2 m). Of the 200 household interviews conducted, 111 were fishers. Seventy-seven percent of fishers operating around the entire lagoon preferred seagrass over any other habitats. Seventeen percent preferred to fish in deeper waters off the coast (identified around the town of Puttalam), and the remaining fisheries utilized mud or sand toward the middle of the lagoon (3–4 m). There was no preference for mangrove or coral among fishers.

Landings and Discards

Sixty-two fish species from 35 families and six invertebrate species from two families were recorded (Appendix A in Suplementary Material). One species of aquatic snake, the little file snake (*Acrochordus granulatus*) was present in two catches but was excluded from further analysis as it is classed as least concern (Sanders et al., 2010). Of the other recorded species, both near threatened (*Dasyatis zugei*, *Gymnura poecilura,* and *Epinephelus malabaricus*) and vulnerable species (*Hippocampus histrix* and *Hippocampus kuda*) were present (IUCN, 2016).

Of the species recorded across catches, 51.5% were routinely discarded, whereas 35.3% were discarded if they were too small. Only 13.2% of species were kept regardless of size. These were six species of invertebrate (*Metapenaeus dobsoni*, *Penaeus indicus*, *P. monodon*, *P. semisulcatus*, *Portunus pelagicus*, *Scylla serrata*) and three species of mullet (*Chelon macrolepis*, *C. parsia*, *Mugli cephalus*). Unwanted species (dead or alive) were indiscriminately discarded onto land and quantitative interview data confirmed that observations of this discarding reflect a general trend with over 50% of fishers confirming this practice (**Figure 2**). An additional 5% of fishers stated that, if non-target species were alive, it would be killed (in the instance of snakes) and left on land. Twenty-two percent of respondents stated that they would return unwanted species to the lagoon (making no specification of mortality status), and 17% said that they returned live species to the lagoon. Less than 2% of respondents would utilize non-target species.

The discarding of by-catch was frequent at the landing site surveyed. Levels of discarding were high and varied between gear types and target types (**Figure 3**). The number of non-target species that were generally discarded per fishing trip was <2 within Fyke net, set trammel net and drift trammel net catches. However, around three species were routinely discarded from trawl catches. For individuals per trip, these numbers were much higher. Generally, fishers targeting finfish discarded much less non-target individuals (16) than fishers targeting shrimp (Fyke = 47; drift trammel = 47; trawl = 64).

When the total number of species and individuals discarded at the site over the study period is taken into account, the magnitude of this issue is realized (**Figure 3**). Over the study period (7 days), at total of 2,752 individuals were discarded from 63 catches. Proportioally, fishers targeting shrimp accounted for the majority of these discards with discards from fkye net catches

TABLE 2 | Fishing effort by gear type, target catch, mesh size and fishing method from 63 fishing trips observed at a landing site in Kalpitiya North, Puttalam Lagoon.

Target catch	Gear type	Mesh size	Gear use observed	Independent trips
Shrimp	Fyke net	1 cm	String of 4–9 nets set overnight ∼12 h	22
Shrimp	Trawl net	2 cm	Overnight sail trawl ∼8 h	10
Shrimp	Trammel net (drifting)	4.5/1.5/4.5 inch	Overnight net deployment ∼8 h	19
Fish	Trammel net (set)	6/2/6 inch	Overnight net deployment and retrievals ∼3 h	12

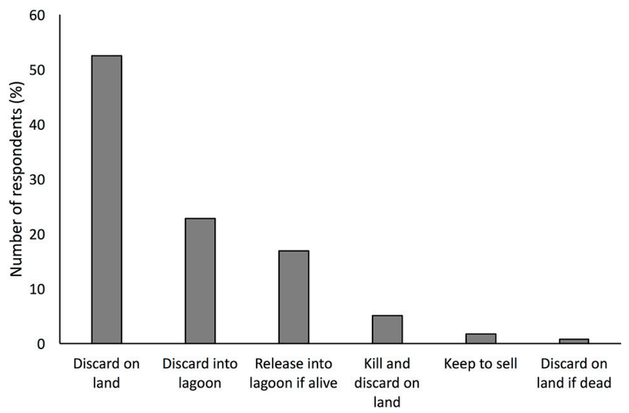

FIGURE 2 | Outcome of by-catch collected by fishermen within Puttalam Lagoon as reported by respondents in the Divisional Secretariats of Kalpitiya, Puttalam, and Wanathawilluwa (Sri Lanka).

being highest (1,040 individuals) and discards from set trammel net catches being lower (191). Compared to discarded species, the total number of individuals (774) that were retained throughout the study was low. There was little difference between the number of species retained per fishing trip across gears and target types, indicative of a general low preference for non-target species.

Catch Variation among Gear Types and Target Types

Across gear types, there were significant differences in the total number of species caught [$F_{(3,\,59)} = 4.49$, $p < 0.05$] and the number of target species caught [$H_{(3)} = 17.831$, $p < 0.001$]. The magnitude of by-catch (number of non-target species caught) [$F_{(3,\,59)} = 6.545$, $p < 0.001$] also differed significantly across gear types. Wind-powered trawl nets had the highest total catch and by-catch rates per trip, catching on average 14.30 ± 1.34 species, where 11.90 ± 1.33 species were considered by-catch, amounting to over 80% of species caught. Drifting trammel nets caught a total of 13.56 ± 0.92 species where 11.32 ± 0.89 were considered by-catch, amounting to over 80% of species caught. Set trammel nets consistently had the lowest total catch and lowest by-catch. On average, 9.92 ± 0.81 species where caught using this gear type and 6.67 ± 0.77 species were considered by-catch. This gear type also had the highest target catch per trip (3.25 ± 0.13) in comparison to the other three gears (all <3 target species per trip; **Figure 4**).

Target species had a strong influence on catch composition. The total number of species caught when shrimp were targeted (12.76 ± 5.12), was significantly higher than when finfish were targeted [9.92 ± 8.11; $t_{(61)} = -2.495$, $p < 0.05$]. Significant differences in the amount of by-catch were observed between target types [$t_{(61)} = -3.267$, $p < 0.05$] where those targeting shrimp (10.37 ± 0.52) catch a higher number of unwanted species than those targeting finfish (6.67 ± 0.77). Similarly, the number of target species caught differed with target type. Fishers targeting shrimp (2.39 ± 0.07) caught significantly fewer target species than those targeting finfish [3.25 ± 0.13; $U_{(61)} = 99$, $z = -4.045$, $p < 0.001$].

Target catch also had a strong influence on the species that were caught, retained and discarded. The common silver biddy (*Gerres oyena*) was present in nearly 100% of catches from fishers targeting shrimp. Over 50% of these were juvenile and always discarded (**Figure 5**). In total, a recorded 577 individuals were discarded over the survey period by shrimp fishers. The streaked spinefoot (*Siganus javus*) was present in over 80% of shrimp catches, where nearly all were juvenile. Of the 10 by-catch species most common in shrimp catches, individuals from five of these species were always discarded and individuals from the five other species kept if large enough.

Fishers targeting finfish discarded fewer species, but the proportion of juveniles were high in six of the 10 species most present in catches (**Figure 6**). For example, only juvenile *S. javus* were present, and were third most common fish across catches and were routinely discarded if they were small. *G. oyena* was also frequent in finfish catches and always discarded regardless of size. In total, a recorded 76 individuals were discarded. Unlike shrimp catches, *G. oyena* were present mainly as adults in finfish catches. Only the most common species caught in catches, *C. macrolepis*, was always kept, and the eight-remaining species were retained only if they were large enough.

Impact of Gear Type on Catch Assemblage

Differences in average catch weight across gear types were not reflective of the number of individuals caught. Finfish fishers, who only used set trammel nets, routinely caught the least species and had the highest total catch weight per trip (12.7 ± 3.7 kg), made up entirely of finfish (**Figure 7**). Shrimp fishers caught a higher number of species per trip than finfish fishers, but landed lower biomass, characteristically landing similar weights of both finfish and shrimp. Fishers using drifting trammel nets caught more finfish (2.1 ± 0.8 kg), in terms of weight than shrimp (1.0 ± 1.0 kg), whereas those (**Figure 7**). Concerning weight, around

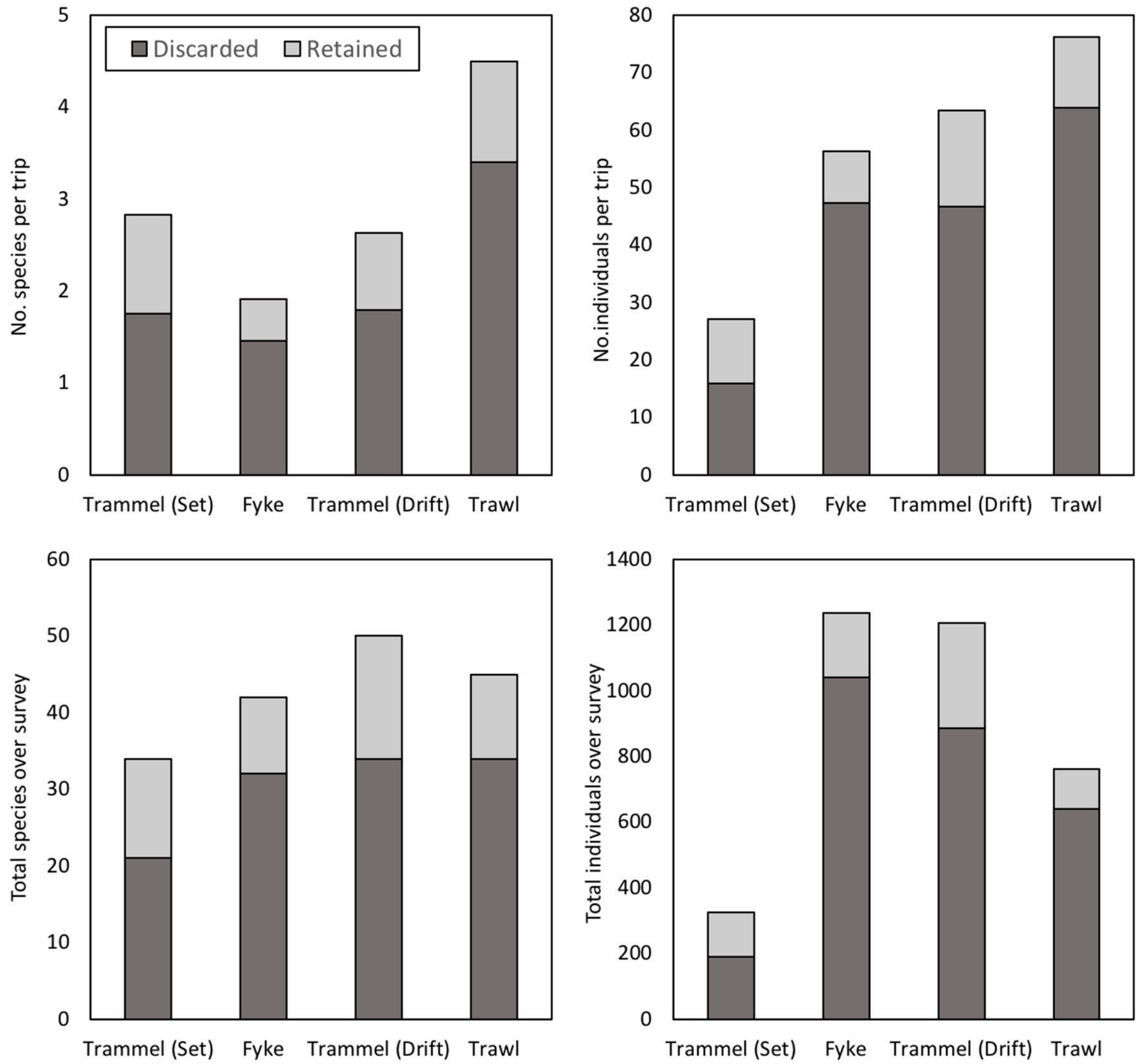

FIGURE 3 | Number of discarded and retained individuals and species per fishing trip and the total number of discared and retained individuals and species during a landing survey of four gear types (set trammel net, fyke net, drifting trammel net, and trawl net) used within Puttalam Lagoon (Sri Lanka).

67% of drifting trammel net catches, and around 44% of fyke and trawl catches, were considered by-catch.

The taxonomic composition of by-catch was similar between gear types, with all discards being finfish. Additionally, the age and life stage of by-catch as a whole did not differ significantly across gear types, with all gear types having a similar proportion of juveniles [$H_{(3)} = 3.586$, $p = 0.310$] and adult [$H_{(3)} = 4.573$, $p = 0.206$]. Wind operated trawl nets caught the most juveniles, where, on average 65.6 ± 42.5% of by-catch was juvenile. By-catch from fyke nets included 61.8 ± 44.3% juveniles. Set and drifting trammel nets had an adult by-catch of 53.2 ± 47.4 and 51.9 ± 46.2%, respectively. Similarly, there was no difference in the proportion of juveniles [$U_{(239)} = 4344.5$, $z = -1.889$, $p = 0.059$] and adults [$U_{(239)} = 4762.5$, $z = -0.910$, $p = 0.363$] between target species. However, fishers targeting finfish caught more adults than those targeting shrimp.

S. javus and *G. oyena* were the most common species caught in gear types. *S. javus* was present in 83.3% of set trammel net catches, 86.4% of fyke net catches, 68.4% of drifting trammel net catches, and 90% of wind-powered trawls. *G. oyena* occurred in 75% of set trammel net catches, 95.5% of fyke net catches and all drifting trammel net and trawl net catches. Across all gear types, the majority of *S. javus* individuals caught were juvenile, with <1% mature individuals. Fish from the Leiognathidae family were also common within gears targeting shrimp, and mostly present as juveniles. The giant catfish (*Netuma thalassina*) was frequently landed, more so in gears targeting shrimp. No adults of this species were recorded. This was true for other key species such as the pink ear emperor (*Lethrinus lentjan*), the blackspot snapper (*Lutjanus fulviflamma*) and the greasy grouper (*E. malabaricus*), which, although less abundant, were only present as juveniles. Fish from the Terapontidae family

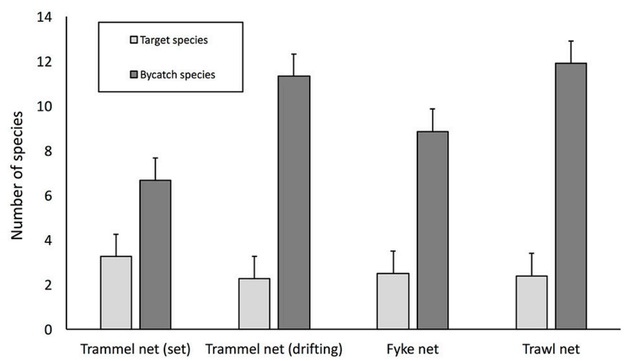

FIGURE 4 | The mean (±*sd*) number of species caught by four gear types (set trammel net, fyke net, drifting trammel net, and trawl net) within Puttalam Lagoon (target species, light gray; by-catch, dark gray).

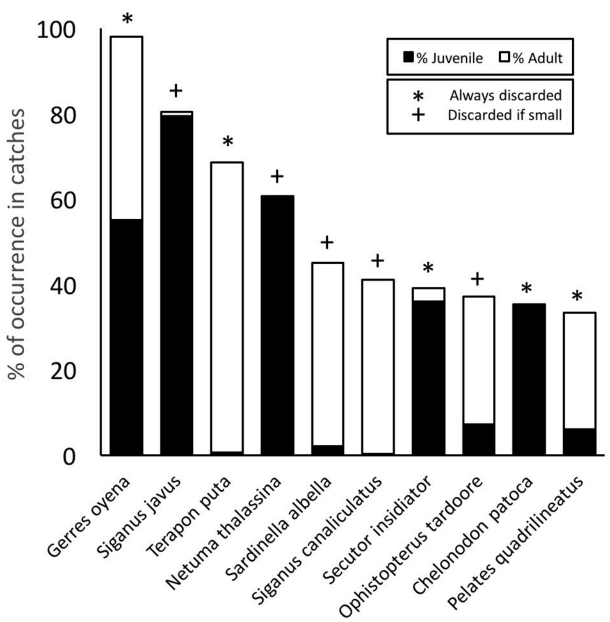

FIGURE 5 | The 10 most common species caught (proportion of juveniles and adults) in catches from fishers targeting shrimp within Puttalam Lagoon (Sri Lanka). The common destination for individuals of these species (* always discarded, + discarded if small) is also provided.

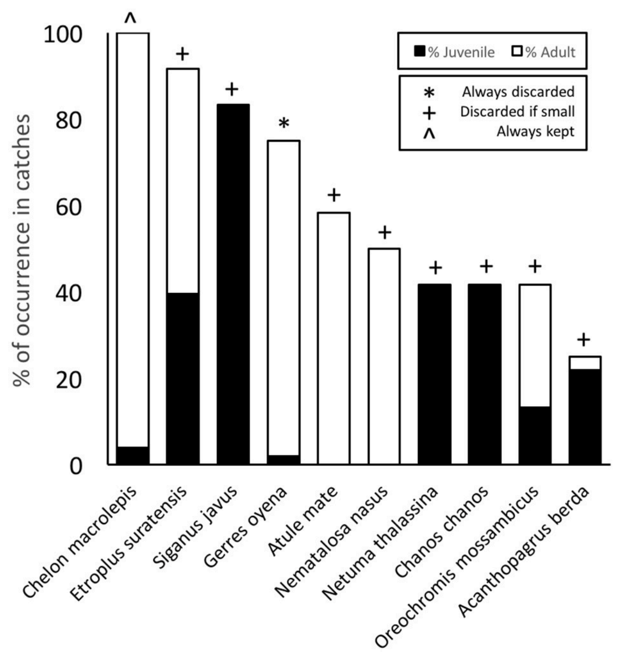

FIGURE 6 | The 10 most common species (proportion of juveniles and adults) caught in catches from fishers targeting finfish within Puttalam Lagoon (Sri Lanka). The common destination for individuals of these species (* always discarded, + discarded if small, ^ always kept) is also provided.

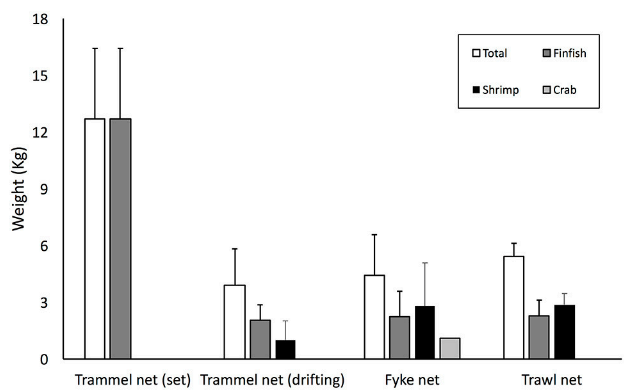

FIGURE 7 | The mean (±*sd*) weight of individual catches caught using four gear types (set trammel net, fyke net, drifting trammel net, and trawl net) within Puttalam Lagoon (Sri Lanka), split between total weight (white), weight of finfish (dark gray), weight of shrimp (black), and weight of crab (light gray).

were mostly present as adults. Other *Siganus* spp., the white-spotted spinefoot (*Siganus canaliculatus*) and the bronze-lined spinefoot (*Siganus insomnis*) were present, but were less frequent and caught as adults (**Figure 5**).

Species assemblages of the total catch differed for gear type. Assemblages separated into distinct groupings within an nMDS ordination plot (**Figure 8**). Differences were significant (ANOSIM: $R = 0.73$, $p < 0.01$) with all pairwise comparisons showing similar significant differences ($P < 0.01$). Similarity within drift Trammel net landings (SIMPER) was driven mostly by *G. oyena, P. indicus*, and *P. semisulcatus* (top three species comprising 45% of the similarity). Similarities within set Trammel net landings were driven by *C. macrolepis, E. suratensis* and *S. javus* (58% of the similarity). Within Fyke net landings similarity was driven by *P. semisulcatus, G. oyena,* and *S. javus* (comprising 45% of the similarity). Within trawl net landings this similarity was the result of *G. oyena, P. semisulcatus,* and *M. dobsoni* (top three species accounting for 40% of the similarity).

Species of Commercial Value

Market surveys revealed that fish from three families (Mugilidae, Siganidae, and Ariidae) were routinely sold and considered "*high*

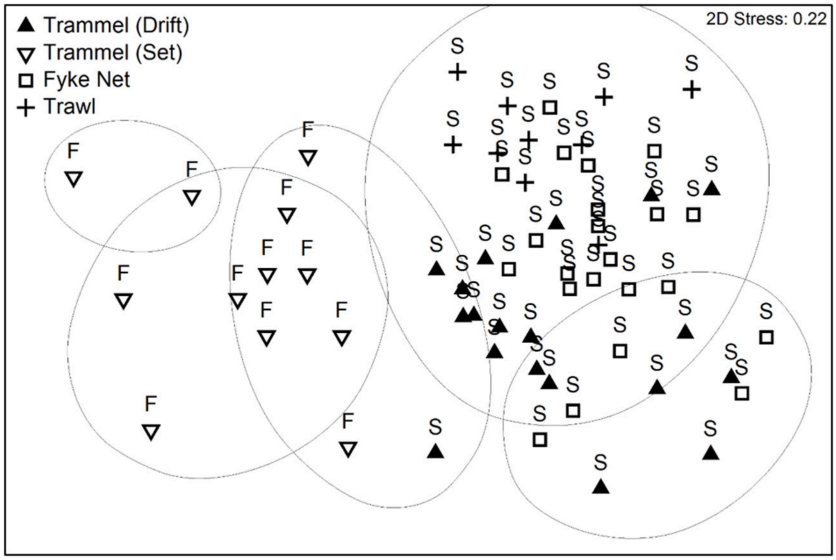

FIGURE 8 | MDS ordination of fish and motile invertebrate assemblages caught in different fishing gear within Puttalam Lagoon (Sri Lanka). Ordination is superimposed with Bray Curtis similarity clusters at the 40% (black lines) level. The target taxa of the fishing gear are indicated to be either F, fish or S, shrimp.

value." Six other species were recorded but were less common. Additional interviews with market owners suggested that fish from the Mugilidae and Siganidae families were requested every day, in addition to *E. suratensis*, yet the latter species was not frequently observed during the survey. Four species of shrimp, *M. dobsoni*, *P. indicus*, *P. semisulcatus,* and *P. monodon,* and two species of crab, the blue swimmer crab (*P. pelagicus*) and the mud crab (*S. serrata*), were recorded in markets and considered "*high value.*" However, only *M. dobsoni, P. pelagicus,* and *S. serrata* were in demand at the household level and *P. indicus, P. semisulcatus,* and *P. monodon* were sold for export via a broker in Puttalam.

Fish from the mullet family were most commonly observed, occurring in 80% of market surveys. These species were also the most abundant in terms of biomass with an average daily stock of 47.3 ± 65.8 kg. Fish from the Siganidae and Ariidae families were also commonly found in 70 and 60% of surveys respectively but regular stock weight of these was far less at 11.1 ± 7.3 and 3.8 ± 2.1 kg, respectively.

Shrimp was the most important invertebrate for over 65% of respondents. Fish from the Mugilidae family were the preferred food fish for 37% of interview respondents, 20% of respondents stated they were the second most important and a further 13% stating that they were the third most important food fish. Fish from the Siganidae family were noted as the second most important fish, with 12% of respondents stating that it was their first preference, 15% stating it as their second and a further 10% stating it as their third most important food fish. Highly discarded species, *G. oyena* and fish from the Leiognathidae family, were recorded as having some importance for food, with 7% of respondents stating that *G. oyena* was third most important in their diet, and 2% and 3% of respondents stating that *Leiognathidae* sp. were second and third most important within their diet, respectively.

DISCUSSION

Small-scale fisheries (SSF) contribute to the livelihoods and well-being of one-tenth of the world's population (FAO, 2014), yet traditional management approaches fail to address overfishing, confounded by a poor understanding of how fishers interact with the marine environment (Fulton et al., 2011; Kittinger et al., 2014). Using an interdisciplinary approach, the present study highlights the by-catch concerns of a SSF in Sri Lankan lagoon; a fishery not characteristically dissimilar to other lagoonal fisheries around the globe (Mathew, 1991; Amarasinghe et al., 1997; Panini, 2001; Kalikoski et al., 2002; Seixas and Berkes, 2003; Lobe and Berkes, 2004).

We surveyed landings from four major gear types that are used within the lagoon all year round. We found that by-catch, that is species that were caught but not the target, comprised a large proportion of the catch from all of them. However, a distressing finding of the study was that a large number of these by-catch species were discarded. During the survey period, a total of 2,757 individuals were indiscrimatively discarded from 63 fishing trips at one landing site alone. For example, all 653 individuals of *G. oyena* that were caught were discarded (Appendix A in Supplementary Material). Similarily, all terapon and puffer individuals, over 350 and 200, respectively, were discarded, which places this issue in context. Additionally, for all 63 trips observed, 100% of the catch was sorted on land, and no fish were returned to the sea. Of the 68 taxa recorded in catches, only nine species were always retained. Thirty-five species were always discarded, regardless of size and the remainder were only retained for consumption if they were large.

Non-target species were not the only individuals that were discarded. Despite being a target fish, nearly 550 juvenile *S. javus* individuals were discarded due to small size but none were replaced back into the lagoon. This was similar for other important food fishes. These included species of Emperor, Grouper, Snapper, Biddy, and Barracuda (de La Torre-Castro et al., 2014; Unsworth et al., 2014) that are regarded high-value food fish locally and in other areas of the Indo-Pacific (de La Torre-Castro et al., 2014; Unsworth et al., 2014). In addition to these concerns, we also revealed the presence of species listed as either near threatened (IUCN, 2016) or vulnerable to extinction (IUCN, 2016). This included two near threatened species of ray, and two vulnerable species of seahorse, *H. histrix* and *H. kuda* (Wiswedel, 2012; Aylesworth, 2014). The two species of seahorse were discarded, despite the fact that both species are considered high value (for traditional medicine) and widely traded in the region (Giles et al., 2006; Perry et al., 2010).

The fishery analyzed here reported by-catch and discard levels of high concern, but it is difficult to place these findings in the context of similar fisheries as quantitative estimates from artisanal fisheries globally are virtually non-existent (Davies et al., 2009) and generally based on reconstructions (Pauly and Zeller, 2016; Zeller et al., 2017).

The species assemblages caught by all four gear types differed. Despite catching high levels of by-catch, fishers targeting finfish with set trammel nets were most selective, with all catches grouped (58% of the similarity) based on the three target species, *C. macrolepis, E. suratensis,* and *S. javus*. Fishers targeting shrimp however were less selective. While shrimp species were responsible for much of the similarities within species assemblages, non-target species such as *G. oyena* (top three species in drift trammel, fyke, and trawl net) and *S. javus* were also responsible for similarities. This is characteristic of the unselective nature of shrimp fishing, aimed at maximizing total catch regardless of effect on other species.

Wild shrimp fisheries are the major fishery of Puttalam lagoon with over half of its fishers solely targeting shrimp. Over 80% of fish landings recorded were from shrimp fishers. Shrimp exports account for ∼50% of the total export earnings from Sri Lankan fisheries (Munasinghe et al., 2010), where it is their second most valuable export fishery (NARA, 2007). Over 90% of shrimp are exported, mostly to Japan but followed by the USA and countries of the European Union (Munasinghe et al., 2010). Before the end of the civil war, the majority of shrimp was harvested from farms, leading to the illegal use of state lands and mangrove destruction (Bournazel et al., 2015). However, poor construction lead to a variety of environmental and socioeconomic effects that hindered the growth and sustainability of shrimp farming within the lagoon area (Cattermoul and Devendra, 2002).

Shrimp fishers landed by-catch made up of multiple species of finfish. This by-catch was considered to hold no financial value but represents the removal of species with high ecological value (e.g., key functional groups). In comparison, fishers targeting finfish had significantly lower by-catch. However, both groups caught significant numbers of juveniles, with locally illegal gears such as fyke nets and trawl's resulting in the highest juvenile catch. This could potentially contribute to the detriment of adult species recruitment and future economic loss for the region (Najmudeen and Sathiadhas, 2008) through growth overfishing. Reflective of the issues of exploitation for fisheries sustainability, in this sense, it is somewhat difficult to label this fishery which incorporates elements of growth, recruitment and ecosystem overfishing, as well as classical and Malthusian overfishing (Pauly and Chua, 1988; Pauly, 1994). The number of species reported here as by-catch present serious concerns, where the functioning of an ecosystem is likely to decrease when removed species have key roles (Duffy, 2002; Andelman and Willig, 2003). The issues here cannot be solved by changes to the fisheries sector alone, and require alternative land-based livelihood opportunities and a strengthening of social and community networks (Pauly, 1994).

It is of no surprise that fishers have turned to shrimp, instead of finfish, for income, with shrimp farming within the lagoon area being unsustainable (Cattermoul and Devendra, 2002) and somewhat in decline (Munasinghe et al., 2010). With shrimp being highly sought after by export markets in Japan, the USA and the European Union, it is clear that professional fishers have since looked for ways to revive and expand a once widespread shrimp-farm industry and have since exploited the lagoon shrimp-fishery. Fishers used multiple gears to target shrimp, notably Fyke nets, wind-powered trawl nets, and drifting trammel nets. Although trammel nets are legal, the other two gears are illegal, with little documentation on their use in the lagoon existing (DFAR, 2013). The most commonly used gears at the landing site were fyke and drifting trammel nets, most likely due to their ease of deployment, meaning that the fishers did not have to be present. Set trammel nets and wind-powered trawls were far less common, with only a handful of fishers using these gears.

While this study documented landings at only one site, we believe that it is a fair characterization of the entire lagoon. While the finfish fishery is seasonal, and fishing activity generally lasts from October to April within the lagoon, shrimp are targeted all year long (IUCN, 2012). This study was conducted during August, during the southwest monsoon when semi-professionaland subsistence fishers make the most of the rainfall for agriculture suggesting that this snapshot likely underestimated the current exploitation. The majority of fishers operating within the lagoon use non-motorized traditional craft (NTRB), of which 1,204 are registered. Of these, 360 boats engage in mixed trammel net fishing (set and drift). Additionally, all gear types surveyed here are used all year round (DFAR, 2013). No documented evidence exists for catch composition for the entire lagoon, but anecdotal observations and discussions with fishers across the lagoon area suggest that fishing practices observed in Kalpitiya are characteristic of the lagoon. Even if the magnitude of by-catch observed in the present study reflects an extreme for SSF, anecdotal evidence from other countries such as Myanmar, Cambodia, and Indonesia suggest that it is not rare. Additionally, socio-economic data confirmed that the number of food fish species demanded by consumers was low—despite being the opposite elsewhere. Fish from the Muglidae and Siganidae families were preferred over others. However, other species, with

FIGURE 9 | By-catch was high in shrimp catches (which were always sorted on the shore). Unwanted species were left for dogs and birds to consume.

lower quality meat, such as those from the Ariidae family, were frequently sold but considered far less important for diet by respondents. Many of the species found within local markets or listed by respondents were largely discarded by fishermen regardless of potential economic gain through sale or subsistence value. Puttalam lagoon suffers from high levels of poverty and food insecurity (IUCN, 2012). Specifically, 32% of the people around the lagoon live below the poverty line (DFAR, 2013). This study, therefore, highlights two potentially widespread alarming issues: (1) unreported SSF by-catch (non-target) may be much higher than previously thought with associated implications for sustainable fisheries and (2) valuable food fishes are being discarded (often dead or dying) in areas characterized by poverty and food insecurity (IUCN, 2012; DFAR, 2013).

So why are fishers discarding fish with either clear commercial or high nutritional value (**Figure 9**)? One answer is that it may reflect limited community integration in fishery activity and poor social networks, minimizing the capacity for discards to reach potential benefactors. It may also reflect a social and cultural preference for alternative species that currently remain available. Given the current climate of high food insecurity and growing resource scarcity, the discard of valuable food fishes is an issue that needs to be addressed. Given that the vast majority of policy and practice in marine ecosystem management targets human activities, a thorough understanding of fishers' behaviors, such as those described here, is pivotal as it provides a qualitative understanding of the complex interactions people and the environment (Fulton et al., 2011). This information is key in areas where landings are not thoroughly recorded or reported.

Although the sometimes unsustainable and destructive nature of SSF has been documented in the literature (D'agrosa et al., 2000; Peckham et al., 2007), this study is the first detailed case study to characterize the associated and extensive finfish by-catch in Sri Lankan Lagoon. Given the growing need to strive for sustainable fisheries (Pauly, 2006) for food security, the present study underlines the need for management of SSF to consider by-catch, that is the non-target catch, as a potentially serious threat to the ecosystem.

ETHICS STATEMENT

This study was carried out in accordance with recommended procedures provided by Cardiff University. However, due to the nature of the study, household respondents were given information about the project and questionnaire and provided verbal consent (rather than written consent) for their information to be used prior to continuing with the interview. Following guidelines from Cardiff University, Ethical approval was not needed for the measurement of landed fish and invertebrates, but relevant permits in this instance were sought from government institutes.

AUTHOR CONTRIBUTIONS

LC-U, RU, and BJ: Conceived the study; BJ and SU: Conducted the study; BJ and RU: Analyzed the results; BJ, RU, and LC-U: Wrote and reviewed the manuscript.

ACKNOWLEDGMENTS

This work was supported by a grant from the Sustainable Places Research Institute at Cardiff University. We specifically thank the fishers who contributed to the data collection effort and participated in the study.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2018.00052/full#supplementary-material

REFERENCES

Amarasinghe, U., Chandrasekara, W., and Kithsiri, H. (1997). Traditional practices for resource sharing in an artisanal fishery of a Sri Lankan estuary. *Asian Fish. Sci.* 9, 311–324.

Andelman, S. J., and Willig, M. R. (2003). Present patterns and future prospects for biodiversity in the Western Hemisphere. *Ecol. Lett.* 6, 818–824. doi: 10.1046/j.1461-0248.2003.00503.x

Aylesworth, L. (2014). *Hippocampus kuda [Online]. The IUCN Red List of Threatened Species 2014: e.T10075A16664386.* doi: 10.2305/IUCN.UK.2014-3.RLTS.T10075A16664386.en (Accessed July 26, 2016).

Berkes, F., Mahon, R., McConney, P., Pollnac, R., and Pomeroy, R. (2001). *Managing Small-Scale Fisheries: Alternative Directions and Methods.* Ottawa, ON: International Development Research Centre.

Berkes, F., and Seixas, C. S. (2005). Building resilience in lagoon social–ecological systems: a local-level perspective. *Ecosystems* 8, 967–974. doi: 10.1007/s10021-005-0140-4

Bournazel, J., Kumara, M. P., Jayatissa, L. P., Viergever, K., Morel, V., and Huxham, M. (2015). The impacts of shrimp farming on land-use and carbon storage around Puttalam lagoon, Sri Lanka. *Ocean Coast. Manag.* 113, 18–28. doi: 10.1016/j.ocecoaman.2015.05.009

Carpenter, K. E., Abrar, M., Aeby, G., Aronson, R. B., Banks, S., Bruckner, A., et al. (2008). One-third of reef-building corals face elevated extinction risk from climate change and local impacts. *Science* 321, 560–563. doi: 10.1126/science.1159196

Cattermoul, N., and Devendra, A. (2002). *Effective Management for Biodiversity Conservation in Sri Lankan Coastal Wetlands: The Ecological Footprint of Shrimp Farming in Chilaw*. Final report, A-4, Project EMBioC, University of Portsmouth, Portsmouth.

Chuenpagdee, R. (2011). "Too big to ignore: Global research network for the future of small-scale," in *World Small-Scale Fisheries - Contemporary Visions,* ed R. Chuenpagdee (Delft: Eburon), 383–394.

Clarke, K. R. (1993). Non-parametric multivariate analysis of changes in community structure. *Austr. J. Ecol.* 18, 117–143. doi: 10.1111/j.1442-9993.1993.tb00438.x

Clarke, K. R., and Gorley, R. N. (2006). *PRIMER v6: User Manual/Tutorial.* Plymouth: PRIMER-E Ltd.

Collette, B. B., Carpenter, K. E., Polidoro, B. A., Juan-Jordá, M. J., Boustany, A., Die, D. J., et al. (2011). High value and long life-double jeopardy for tunas and billfishes. *Science* 333, 291–292. doi: 10.1126/science.1208730

Croxall, J. P., Butchart, S. H., Lascelles, B., Stattersfield, A. J., Sullivan, B., Symes, A., et al. (2012). Seabird conservation status, threats and priority actions: a global assessment. *Bird Conserv. Int.* 22, 1–34. doi: 10.1017/S0959270912000020

D'agrosa, C., Lennert-Cody, C. E., and Vidal, O. (2000). Vaquita bycatch in Mexico's artisanal gillnet fisheries: driving a small population to extinction. *Conserv. Biol.* 14, 1110–1119. doi: 10.1046/j.1523-1739.2000.98191.x

Davies, R. W. D., Cripps, S. J., Nickson, A., and Porter, G. (2009). Defining and estimating global marine fisheries bycatch. *Mar. Policy* 33, 661–672. doi: 10.1016/j.marpol.2009.01.003

Dayton, P. K., Thrush, S. F., Agardy, M. T., and Hofman, R. J. (1995). Environmental-effects of marine fishing. *Aquat. Conserv. Mar. Freshw. Ecosyst.* 5, 205–232. doi: 10.1002/aqc.3270050305

de La Torre-Castro, M., Di Carlo, G., and Jiddawi, N. S. (2014). Seagrass importance for a small-scale fishery in the tropics: the need for seascape management. *Mar. Pollut. Bull.* 83, 398–407. doi: 10.1016/j.marpolbul.2014.03.034

Department of Census and Statistics (2011). Colombo: Department of Census and Statistics. Available online at: http://www.statistics.gov.lk/Tsunami/final/Puttalam/index.htm (Accessed July 6, 2015).

DFAR (2013). *Fisheries Development and Management Plan of Puttalam Lagoon, Regional Fisheries Livelihoods Programme for South and Southeast Asia (GCP/RAS/237/SPA): Field Project Document 2013/LKA/CM/2.*

Duffy, J. E. (2002). Biodiversity and ecosystem function: the consumer connection. *Oikos* 99, 201–219. doi: 10.1034/j.1600-0706.2002.990201.x

Dulvy, N. K., Baum, J. K., Clarke, S., Compagno, L. J. V., Cortes, E., Domingo, A., et al. (2008). You can swim but you can't hide: the global status and conservation of oceanic pelagic sharks and rays. *Aquat. Conserv. Mar. Freshw. Ecosyst.* 18, 459–482. doi: 10.1002/aqc.975

Dulvy, N. K., Sadovy, Y., and Reynolds, J. D. (2003). Extinction vulnerability in marine populations. *Fish Fish.* 4, 25–64. doi: 10.1046/j.1467-2979.2003.00105.x

FAO (2014). *The State of World Fisheries and Aquaculture (SOFIA) 2014. Fisheries and Aquaculture Department*. Rome: Food and Agricultural Organization of the United Nations.

Fennessy, S. T., and Everett, B. I. (2015). "Fisheries' bycatch, an updated assessment of the status in the Southwest Indian Ocean," in *Offshore Fisheries of the Southwest Indian Ocean: Their Status and the Impact on Vulnerable Specie,* eds R. P. Van Der Elst and B. I. Everett (Durban: Oceanographic Research Institute (ORI) and the Western Indian Ocean Marine Sciences Association (WIOMSA)), 287–302.

Ferretti, F., Worm, B., Britten, G. L., Heithaus, M. R., and Lotze, H. K. (2010). Patterns and ecosystem consequences of shark declines in the ocean. *Ecol. Lett.* 13, 1055–1071. doi: 10.1111/j.1461-0248.2010.01489.x

Froese, R., and Pauly, D. (2016). *FishBase*. Available online at: http://www.fishbase.org/ (Accessed June 17, 2016).

Fulton, E. A., Smith, A. D., Smith, D. C., and Van Putten, I. E. (2011). Human behaviour: the key source of uncertainty in fisheries management. *Fish Fish.* 12, 2–17. doi: 10.1111/j.1467-2979.2010.00371.x

Giles, B. G., Ky, T. S., and Vincent, A. C. (2006). The catch and trade of seahorses in Vietnam. *Biodivers. Conserv.* 15, 2497–2513. doi: 10.1007/s10531-005-2432-6

Harmelin-Vivien, M., Harmelin, J., Chauvet, C., Duval, C., Galzin, R., Lejeune, P., et al. (1985). Evaluation Visuelle des Peuplements et Populations de Poissons Méthodes et Problèmes. *Rev. D'Ecol.* 40, 467–539.

Hutchings, J. A. (2000). Collapse and recovery of marine fishes. *Nature* 406, 882–885. doi: 10.1038/35022565

IUCN (2003a). "Biodiversity in Puttalam Lagoon with special reference to poverty alleviation in coastal villages of Vanathavilluwa: Sri Lanka Coponent," in *Regional Technical Assistance for Coastal and Marine Resources Management and Poverty Reduction in South Asia (ADB RETA* 5974*).*

IUCN (2003b). "A special study on assessment of fisheries related livelihoods and infrastructure in Puttalam Lagoon: Sri Lanka Component," in *Regional Technical Assistance for Coastal and Marine Resources Management and Poverty Reduction in South Asia (ADB RETA* 5974*).*

IUCN (2012). "An environmental and fisheries profile of the Puttalam Lagoon system," in *Regional Fisheries Livelihoods Programme for South and Southeast Asia (GCP/RAS/237/SPA).*

IUCN (2016). *The IUCN Red List of Threatened Species*. Available online at: http://www.iucnredlist.org/ (Accessed June 30, 2016).

Jentoft, S., and Chuenpagdee, R. (2015). *Interactive Governance for Small-Scale Fisheries*: Global Reflections. Dordrecht: Springer.

Kalikoski, D. C., Vasconcellos, M., and Lavkulich, L. (2002). Fitting institutions to ecosystems: the case of artisanal fisheries management in the estuary of Patos Lagoon. *Mar. Policy* 26, 179–196. doi: 10.1016/S0308-597X(01)00048-3

Kappel, C. V. (2005). Losing pieces of the puzzle: threats to marine, estuarine, and diadromous species. *Front. Ecol. Environ.* 3, 275–282. doi: 10.1890/1540-9295(2005)003[0275:LPOTPT]2.0.CO;2

Kelleher, K. (2005). "Discards in the world's marine fisheries. An update," in *FAO Fisheries Technical Paper; No. 470* (Rome: FAO).

Kiszka, J., Muir, C., Poonian, C., Cox, T. M., Amir, O. A., Bourjea, J., et al. (2008). Marine mammal bycatch in the southwest Indian Ocean: review and need for a comprehensive status assessment. *West. Indian Ocean J. Mar. Sci.* 7, 119–136. Available online at: http://www.wiomsa.org/download/119-136__kiszka_et_al.pdf

Kittinger, J. N., Koehn, J. Z., Le Cornu, E., Ban, N. C., Gopnik, M., Armsby, M., et al. (2014). A practical approach for putting people in ecosystem-based ocean planning. *Front. Ecol. Environ.* 12, 448–456. doi: 10.1890/130267

Koch, V., Nichols, W. J., Peckham, H., and De La Toba, V. (2006). Estimates of sea turtle mortality from poaching and bycatch in Bahia Magdalena, Baja California Sur, Mexico. *Biol. Conserv.* 128, 327–334. doi: 10.1016/j.biocon.2005.09.038

Lewison, R. L., Crowder, L. B., Wallace, B. P., Moore, J. E., Cox, T., Zydelis, R., et al. (2014). Global patterns of marine mammal, seabird, and sea turtle bycatch reveal taxa-specific and cumulative megafauna hotspots. *Proc. Natl. Acad. Sci. U.S.A.* 111, 5271–5276. doi: 10.1073/pnas.1318960111

Lewison, R., Oro, D., Godley, B., Underhill, L., Bearhop, S., Wilson, R., et al. (2012). Research priorities for seabirds: improving conservation and management in the 21st century. *Endanger. Species Res.* 17, 93–121. doi: 10.3354/esr00419

Lobe, K., and Berkes, F. (2004). The padu system of community-based fisheries management: change and local institutional innovation in south India. *Mar. Policy* 28, 271–281. doi: 10.1016/S0308-597X(03)00087-3

Lopez, A., Pierce, G. J., Santos, M. B., Gracia, J., and Guerra, A. (2003). Fishery by-catches of marine mammals in Galician waters: results from on-board observations and an interview survey of fishermen. *Biol. Conserv.* 111, 25–40. doi: 10.1016/S0006-3207(02)00244-6

Lotze, H. K., Lenihan, H. S., Bourque, B. J., Bradbury, R. H., Cooke, R. G., Kay, M. C., et al. (2006). Depletion, degradation, and recovery potential of estuaries and coastal seas. *Science* 312, 1806–1809. doi: 10.1126/science.1128035

Mathew, S. (1991). *Study of Territorial Use Rights in Small-Scale Fisheries: Traditional Systems of Fisheries Management in Publicat Lake,* Tamil Nadu, *India*.

McClenachan, L., Cooper, A. B., Carpenter, K. E., and Dulvy, N. K. (2012). Extinction risk and bottlenecks in the conservation of charismatic marine species. *Conserv. Lett.* 5, 73–80. doi: 10.1111/j.1755-263X.2011.00206.x

MFARD (2015). *Performance 2015. Maligawatta, Colombo 10.* Ministry of Fisheries and Aquatic Resources Development (MFARD).

Munasinghe, M. N., Stephen, C., Abeynayake, P., and Abeygunawardena, I. S. (2010). Shrimp farming practices in the puttallam district of sri lanka: implications for disease control, industry sustainability, and rural development. *Vet. Med. Int.* 2010:679130. doi: 10.4061/2010/679130

Najmudeen, T. M., and Sathiadhas, R. (2008). Economic impact of juvenile fishing in a tropical multi-gear multi-species fishery. *Fish. Res.* 92, 322–332. doi: 10.1016/j.fishres.2008.02.001

NARA (2007). *Sri Lanka Fisheries Yearbook*. Colombo: National Aquaric Resources Research and Development Agency.

Omar, A. A., Berggren, P., and Narriman, S. J. (2002). *The Incidential Catch of Dolphines in Gillnet Fisheries in Zanzibar*, *Tanzania*.

Panini, D. (2001). "Addressing livelihood issues in conservation-oriented projects: a case study of Pulicat Lake, Tamil Nadu, India," in *Conflict and Cooperation in Participatory Natural Resource Management*, eds R. Jeffery and B. Vira (New York, NY: Palgrave), 63–74.

Pauly, D. (1994). From growth to Malthusian overfishing: stages of fisheries resources misuse. *Tradit. Mar. Resour. Manage. Knowl. Inform. Bull.* 3, 7–14.

Pauly, D. (2006). Major trends in small-scale fisheries, with emphasis on developing countries, and some implications for the social sciences. *Maritime Stud.* 4, 7–22. Available online at: http://www.marecentre.nl/mast/documents/Pauly_Mast2006vol_4no_2_new.pdf

Pauly, D., and Chua, T. (1988). The overfishing of marine resources: socioeconomic background in Southeast Asia. *Ambio* 17, 200–206.

Pauly, D., and Zeller, D. (2016). Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. *Nat. Commun.* 7:10244. doi: 10.1038/ncomms10244

Peckham, S. H., Maldonado Diaz, D., Walli, A., Ruiz, G., Crowder, L. B., and Nichols, W. J. (2007). Small-Scale fisheries bycatch jeopardizes endangered pacific loggerhead turtles. *PLoS ONE* 2:e1041. doi: 10.1371/journal.pone.0001041

Perry, A. L., Lunn, K. E., and Vincent, A. C. (2010). Fisheries, large-scale trade, and conservation of seahorses in Malaysia and Thailand. *Aquat. Conserv. Mar. Freshw. Ecosyst.* 20, 464–475. doi: 10.1002/aqc.1112

Polidoro, B. A., Brooks, T., Carpenter, K. E., Edgar, G. J., Henderson, S., Sanciangco, J., et al. (2012). Patterns of extinction risk and threat for marine vertebrates and habitat-forming species in the Tropical Eastern Pacific. *Mar. Ecol. Prog. Ser.* 448, 93–104. doi: 10.3354/meps09545

Ranasinghe, T. (ed.). (2010). A *Sustainable Financing and Benefit - Sharing Strategy for Conservation and Management* of Puttalam Lagoon. Colombo: Ecosystems and Livelihoods Group Asia & Iucn.

Read, A. J., Drinker, P., and Northridge, S. (2006). Bycatch of marine mammals in US and global fisheries. *Conserv. Biol.* 20, 163–169. doi: 10.1111/j.1523-1739.2006.00338.x

Ricard, D., Minto, C., Jensen, O. P., and Baum, J. K. (2012). Examining the knowledge base and status of commercially exploited marine species with the RAM Legacy Stock Assessment Database. *Fish Fish.* 13, 380–398. doi: 10.1111/j.1467-2979.2011.00435.x

Samarakoon, J., and Samarawickrama, S. (2012). *An Appraisal of Challenges in the Sustainable Management of the Micro-Tidal Barrier-Built Estuaries and Lagoons in Sri Lanka*. Colombo: IUCN Sri Lanka Country Office.

Sanders, K., Murphy, J., Lobo, A., and Gatus, J. (2010). *Acrochordus Granulatus. The IUCN Red List of Threatened Species 2010: e.T176769A7300762.* doi: 10.2305/IUCN.UK.2010-4.RLTS.T176769A7300762.en (Accessed July 26, 2016).

Seixas, C. S., and Berkes, F. (2003). "Dynamics of social-ecological changes in a lagoon fishery in southern Brazil," in *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*, eds F. Berkes, J. Colding, and C. Folke (New York, NY: Cambridge University Press), 271–290.

Shester, G. G., and Micheli, F. (2011). Conservation challenges for small-scale fisheries: bycatch and habitat impacts of traps and gillnets. *Biol. Conserv.* 144, 1673–1681. doi: 10.1016/j.biocon.2011.02.023

Silva, E. I. L., Katupotha, J., Amarasinghe, O., Manthrithilake, H., and Ariyaratne, R. (2013). *Lagoons of Sri Lanka: From the Origins to the Present*. Colombo: International Water Management Institute.

Stevens, K., Frank, K. A., and Kramer, D. B. (2015). Do social networks influence small-scale fishermen's enforcement of sea tenure? *PLoS ONE* 10:e0121431. doi: 10.1371/journal.pone.0121431

Stewart, K. R., Lewison, R. L., Dunn, D. C., Bjorkland, R. H., Kelez, S., Halpin, P. N., et al. (2010). Characterizing fishing effort and spatial extent of coastal fisheries. *PLoS ONE* 5:e14451. doi: 10.1371/journal.pone.0014451

Teh, L. C., and Sumaila, U. R. (2013). Contribution of marine fisheries to worldwide employment. *Fish Fish.* 14, 77–88. doi: 10.1111/j.1467-2979.2011.00450.x

Temple, A. J., Kiszka, J. J., Stead, S. M., Wambiji, N., Brito, A., Poonian, C. N., et al. (2017). Marine megafauna interactions with small-scale fisheries in the southwestern Indian Ocean: a review of status and challenges for research and management. *Rev. Fish Biol. Fish.* doi: 10.1007/s11160-017-9494-x. [Epub ahead of print].

Too-Big-to-Ignore (2017). *Too Big To Ignore*. Available online at: http://toobigtoignore/ (Accessed January 26, 2017).

Underwood, A. J. (1997). *Experiments in Ecology: Their Logical Design and Interpretation Using Analysis of Variance*. Cambridge: Cambridge University Press.

Unsworth, R. K., and Cullen, L. C. (2010). Recognising the necessity for Indo-Pacific seagrass conservation. *Conserv. Lett.* 3, 63–73. doi: 10.1111/j.1755-263X.2010.00101.x

Unsworth, R. K. F., Hinder, S. L., Bodger, O. G., and Cullen-Unsworth, L. C. (2014). Food supply depends on seagrass meadows in the coral triangle. *Environ. Res. Lett.* 9:094005. doi: 10.1088/1748-9326/9/9/094005

Wallace, B. P., Dimatteo, A. D., Bolten, A. B., Chaloupka, M. Y., Hutchinson, B. J., Abreu-Grobois, F. A., et al. (2011). Global conservation priorities for marine turtles. *PLoS ONE* 6:e24510. doi: 10.1371/journal.pone.0024510

Wiswedel, S. (2012). *Hippocampus Histrix. The IUCN Red List of Threatened Species 2012: e.T10070A16644674.* doi: 10.2305/IUCN.UK.2012.RLTS.T10070A16644674.en (Accessed July 26, 2016).

Zeller, D., Cashion, T., Palomares, M., and Pauly, D. (2017). Global marine fisheries discards: a synthesis of reconstructed data. *Fish Fish.* 19, 30–39. doi: 10.1111/faf.12233

Zeller, D., and Pauly, D. (2005). Good news, bad news: global fisheries discards are declining, but so are total catches. *Fish Fish.* 6, 156–159. doi: 10.1111/j.1467-2979.2005.00177.x

Zimmerhackel, J. S., Schuhbauer, A. C., Usseglio, P., Heel, L. C., and Salinas-De-León, P. (2015). Catch, bycatch and discards of the Galapagos Marine Reserve small-scale handline fishery. *PeerJ* 3:e995. doi: 10.7717/peerj.995

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.