



Understanding Gender and Factors Affecting Fishing in an Artisanal Shellfish Fishery

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Fishing strategies, effort and harvests of small-scale fishers are important to understand for effective planning of regulatory measures and development programs. Gender differences in fishing can highlight inequities deserving transformative solutions, but might mask other important factors. We examined fishing modes, fishing frequency, catch-per-unit-effort (CPUE), resource preferences and perceptions of fishery stock among artisanal gastropod (trochus) fishers in Samoa using structured questionnaires and mixed effects models. The fishery has an extremely modest carbon footprint of 18–23 tons of CO₂ p.a., as few fishers used motorized boats. Trochus (*Rochia nilotica*), an introduced gastropod, was the second-most harvested resource, after fish, despite populations only being established in the past decade. Daily catch volume varied according to gender and villages ($n = 34$), and was also affected by fishing effort, experience, assets (boat), and fishing costs of fishers. Boat users had much higher CPUE than fishers without a boat. Fishers who practised both gleaning and diving caught a greater diversity of marine resources; effects that explained otherwise seeming gender disparities. Trochus tended to be ranked more important (by catch volume) by women than men, and rank importance varied greatly among villages. Local ecological knowledge of fishers informed the historical colonization of trochus around Samoa and current trends in population abundance. Fishing efficiency, catch diversity and perspectives about stocks were similar between fishermen and fisherwomen, when accounting for other explanatory variables. Greater importance of these shellfish to women, and gender similarities in many of the fishing responses, underscore the need to ensure equal representation of women in the decision making in small-scale fisheries.

Keywords: small-scale fishing, artisanal fisheries, gender, CPUE, gleaning, shellfish, trochus

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INTRODUCTION

Small-Scale Invertebrate Fisheries

The importance of small-scale fisheries (SSFs) to employment and livelihoods has underpinned the rising interest in this sector among researchers, NGOs and resource managers (Berkes et al., 2000; Chuenpagdee et al., 2006; Batista et al., 2014; Purcell and Pomeroy, 2015). Many SSFs target invertebrates, since resources like shellfish, crabs and octopus are often accessible close to shore

and can be harvested by hand or using simple fishing gears. Invertebrate fisheries can be traced back to 1300 B.C. (Antczak and Antczak, 2006) and can be extensive in terms of fishery production and socioeconomic importance (Leiva and Castilla, 2002; Anderson et al., 2011; Smith and Basurto, 2019).

Women are especially active in artisanal invertebrate fisheries, often for subsistence purposes (Lambeth et al., 2002; Crawford et al., 2010; Harper et al., 2013). They can differ from men in fishing, such as in terms of access or use of fishing grounds (Harper et al., 2013; Fröcklin et al., 2014), catch rates (see Kleiber et al., 2015), catch volumes (Harper et al., 2013), and species targeted (Lambeth et al., 2002). Yet to achieve gender equitable fisheries we must understand more than just their participation rates in fisheries (Williams et al., 2002; Kleiber et al., 2015; Kawarazuka et al., 2017), and critically assess potential gender disparities in fishing practices, ecological knowledge and views about fishery management (WorldFish, 2010; Biswas, 2017). Only through a rigorous assessment of gendered variation among fishers alongside other explanatory variables can we properly understand differential impacts of fishery regulations on fishers and target the right fisher groups for fisher training and development programs. Such research should be carried out across a range of localities in a fishery to best understand gender variation that can arise according to local contexts (Biswas, 2017).

Shellfish fisheries have been important worldwide since prehistory (Antczak and Antczak, 2006; Schapira et al., 2009; Schwerdtner, 2010). Bivalve fisheries, from small artisanal scale to industrial scale, have targeted resources such as scallop and pearl oysters across all continents excluding Antarctica (Shumway and Parsons, 2016). Gastropod fisheries, such as those for abalone, have been significant for many years in several developed countries (Cook, 2014). In general, small-scale shellfish fisheries are especially important to coastal communities in low-income countries (Béné et al., 2010; Gillett and Tauati, 2018). They often produce a low ecological impact, because the animals are harvested by hand and using non-motorized boats resulting in small carbon footprints (Maynou et al., 2013; Koralagama et al., 2017).

Factors Affecting Variation in Fishing and Catches

There is a renowned need for gender inclusion in fisheries science to achieve interdisciplinary management models required by policy makers (Bennett, 2005; Biswas, 2017). Gender is as a key societal organizer (Fröcklin et al., 2013; Sprague, 2016), and consequently used as a means to discriminate fishing activities (Kleiber et al., 2015). Gender encompasses more than just a differentiation between sexes—it also refers to the cultural, normative and social attributes of men and women (Biswas, 2017; de la Torre-Castro, 2019) and further concerns their power, roles and influence (Bennett, 2005). The inclusion of gender in fisheries research illuminates opportunities for transformative pathways to improve fishing livelihoods (Sultana et al., 2002; Bennett, 2005; Kawarazuka et al., 2017; Ameyaw et al., 2020). From a management viewpoint, overlooking the role of women in fisheries can result in underestimation of total fishing pressure

and an incomplete view of seafood harvesting (Harper et al., 2013; Kleiber et al., 2015; Rabbitt et al., 2019).

Women are known to interact with different parts of the marine ecosystem in some fisheries because they can target different animals occurring in different habitats to those fished by men (Weeratunge et al., 2010; Máñez and Pauwelussen, 2016). In the Pacific region, women are strongly involved in SSFs, contributing about half of the SSF landings (Harper et al., 2013). A better understanding of their roles in fisheries could inform development programs and fishery policy. For example, some fisheries can be strongly gender structured, with women participating mostly in postharvest processing tasks (Mojola, 2011; Biswas, 2017), or catching a different composition of species than men (Purcell et al., 2018). Data on the influence of fisherwomen on fishery catches might bolster the case for better inclusion in fisheries decision making. In addition to informing fishery management planning, such inclusion could benefit community cohesion and commitment to resource sustainability (Biswas, 2017).

Estimates of total catch in invertebrate fisheries, along with data on fishing effort, can serve as key reference points for developing fishery management targets and output controls (Caddy, 2004). Such data, and derived data on catch-per-unit-effort (CPUE), are especially valuable for fisheries in the early stages of development (Perry et al., 1999). In this context, potential variation in fishing practices, catches and perceptions among fishers could be affected by a range of factors that should be examined and analyzed together. For instance, the mode of fishing used by a fisher can be influenced by their gender, age and geographic location within a fishery (e.g., village or island of residence) (Hauzer et al., 2013; Kleiber et al., 2015; Purcell et al., 2018). In Samoa, subsistence fishing is reported to be especially high on the island of Savai'i compared to Upolu island where village culture is more influenced by western norms (Techera, 2006). Likewise, resource access in SSFs can depend on socioeconomic status, whereby fishers with more capital items, such as boats, can fish in less-exploited grounds with higher resources abundances further from shore (Siar, 2003; Campling et al., 2012). Fishers with more years of experience in fishing the resource can have different perceptions about whether stocks have declined or increased (Bender et al., 2014; Purcell et al., 2016), and it would be logical to expect them to have higher catch rates due to skills and better knowledge about fishing grounds.

Fuel consumption can directly affect the economic viability of fisheries but also represent a source a greenhouse emission (Tyedmers et al., 2005; Suuronen et al., 2012). The carbon footprints from fisheries can reach similar levels of those of terrestrial livestock industries (Parker and Tyedmers, 2015). There is a growing need worldwide for green goods with reduced energy emissions during the production process (Parker and Tyedmers, 2015), and this is pertinent for production systems developed through foreign-aid funding. Estimates of fishery carbon footprints contribute to more accurate evaluation of national carbon emissions and can help fishery managers to implement measures that improve fuel efficiency (Parker et al., 2018). Data on greenhouse gas emissions of industries such

as fisheries should be especially valuable for Pacific Island governments in their lobbying for greater reduction measures in developed countries.

Trochus: A Staple Resource of the Pacific Islands

Trochus (*Rochia nilotica*; formerly *Trochus niloticus* and *Tectus niloticus*) is a large marine topshell snail that has been translocated around much of the Central-Western Pacific Islands for 80 years (Nash, 1993; Gillett, 2002). Its original geographic distribution was restricted to the Western Pacific and Southeast Asia (Bell et al., 2005). Translocations of broodstock to new places in the Pacific Islands have led to lucrative fisheries. However, the extent of colonization of trochus has been variable among localities (Bell et al., 2005). Understanding the geographic extent of colonization is fundamental to fishery management planning, and could be supported by data on local ecological knowledge of fishers in addition to underwater population surveys.

Traditionally, the principal value of trochus has been in the shell (Nash, 1993). It has a lustrous nacre beneath the outer shell layer and has been widely exported for the manufacturing of shirt buttons and for inlays and handicrafts (Surtida, 2000). In recent years, about 2300 t of trochus shells were exported annually from the Pacific Islands, accounting for about 60% of the international market (Gillett and Tauati, 2018). Shell buttons have been progressively replaced by plastic replicas (ICECON, 1997), so the export trade has been weak and harvesting of the animals has served more for domestic consumption of the flesh.

Trochus were first introduced to Samoa in 1990 to a reef in the far southeast of Upolu island (Gillett, 2002; Lober et al., 2003), but this introduction was apparently unsuccessful in creating any populations of trochus on reefs in Samoa (Tiitii and Aiafi, 2015). In 2003 and 2006, adult broodstock trochus were introduced to Samoa from Fiji and Vanuatu, through funding from Australia's foreign aid program (ACIAR Project FIS/2001/085). The intention was to provide a new fishery resource for people to get food and income. The Samoan Ministry of Agriculture and Fisheries started finding large numbers of trochus being sold in markets and roadside stalls from about 2009, and the resource quickly became a popular local seafood (Tiitii and Aiafi, 2015).

Aims and Objectives of This Study

The main objective of this study was to diagnose the status of Samoa's nascent trochus fishery and inform fishery management on key factors affecting fishing practices and perceptions of fishers. Our main research questions were: Do fishing activities and practices of fishers (e.g., gear use, fishing frequency, catch rates, catch composition) vary between men and women or among villages and islands when other factors to distinguish fishers are taken into account? What can the local ecological knowledge of fishers tell us about the introduced gastropod stocks? What are fishers' perceptions about potential management regulations for the fishery, and do those differ depending on location, gender or age of fishers? Therefore, we used questionnaire data collected on fishing modes, effort,

catches, and perceptions of artisanal fishers in Samoa, and robust mixed-model analyses, to examine the influence of multi-level factors (e.g., gender, fisher age, boat use, island, and village within island) on variation in these responses among the fishers. The research approach allows for a critical appraisal of geographic and gendered disparities in fishing responses when other factors to distinguish fishers are taken into account.

We further took the opportunity of our data collection to calculate the spatial extent of trochus captures in Samoa and to examine the carbon footprint of the fishery by extrapolating our data on boat fuel used by the fishers. Data on fishers' first observations of trochus on the reefs, their perceptions about recent trends in stock abundance, and opinions about regulatory measures (minimum legal size limits and seasonal closures), allows us to provide a further case of using local knowledge to inform fishery management.

MATERIALS AND METHODS

Study Sites

The study was conducted in November and December 2018 in Samoa (formerly Western Samoa), an autonomously governed country in the Polynesian cultural region of the Pacific Islands (Figure 1). The fishery for trochus (*Rochia nilotica*) in Samoa has been largely unregulated. There has been a minimum size limit for capture (90 mm basal shell width), but the regulation has been weakly enforced.

We evaluated trochus fishing in coastal villages around both main islands: Upolu ($n = 19$) and Savaii ($n = 15$). Villages of reasonable population size (estimated to have at least 6 trochus fishers), and where trochus was known to be collected, were chosen in consultation with the Fisheries Division of the Ministry of Agriculture and Fisheries, Samoa. The 34 study villages represent 20% of villages in Samoa where the Ministry of Fisheries believed that trochus was being harvested.

Data Collection

Around 9 fishers (range = 6–13, mean = 8.9, median = 9) were interviewed in each village, subject to their availability. Some villages only had fewer than ten fishers, so it was impossible to have similar sample sizes among villages. Apart from consulting with the village mayor, we used 'snowball' sampling to locate active fishers based on knowledge from existing interviewees. We also employed a gender-inclusive approach (Kleiber et al., 2015), whereby women fishers were interviewed where possible in order to ensure their representation in our surveys (Table 1). The sampling was open to any person who collected trochus within the past year, regardless of the frequency or purpose of fishing.

The questionnaire surveys were approved (Southern Cross University: ECN-18-204) for ethical human research and overseas research in accord with the Australian National Statement on Ethical Conduct in Human Research, 2007. In Samoa, the Ministry of Women's Affairs granted additional approval. Through separate prior visits, we also obtained authorization to conduct the interviews from the chiefs or mayors of each village. Information sheets in Samoan were firstly

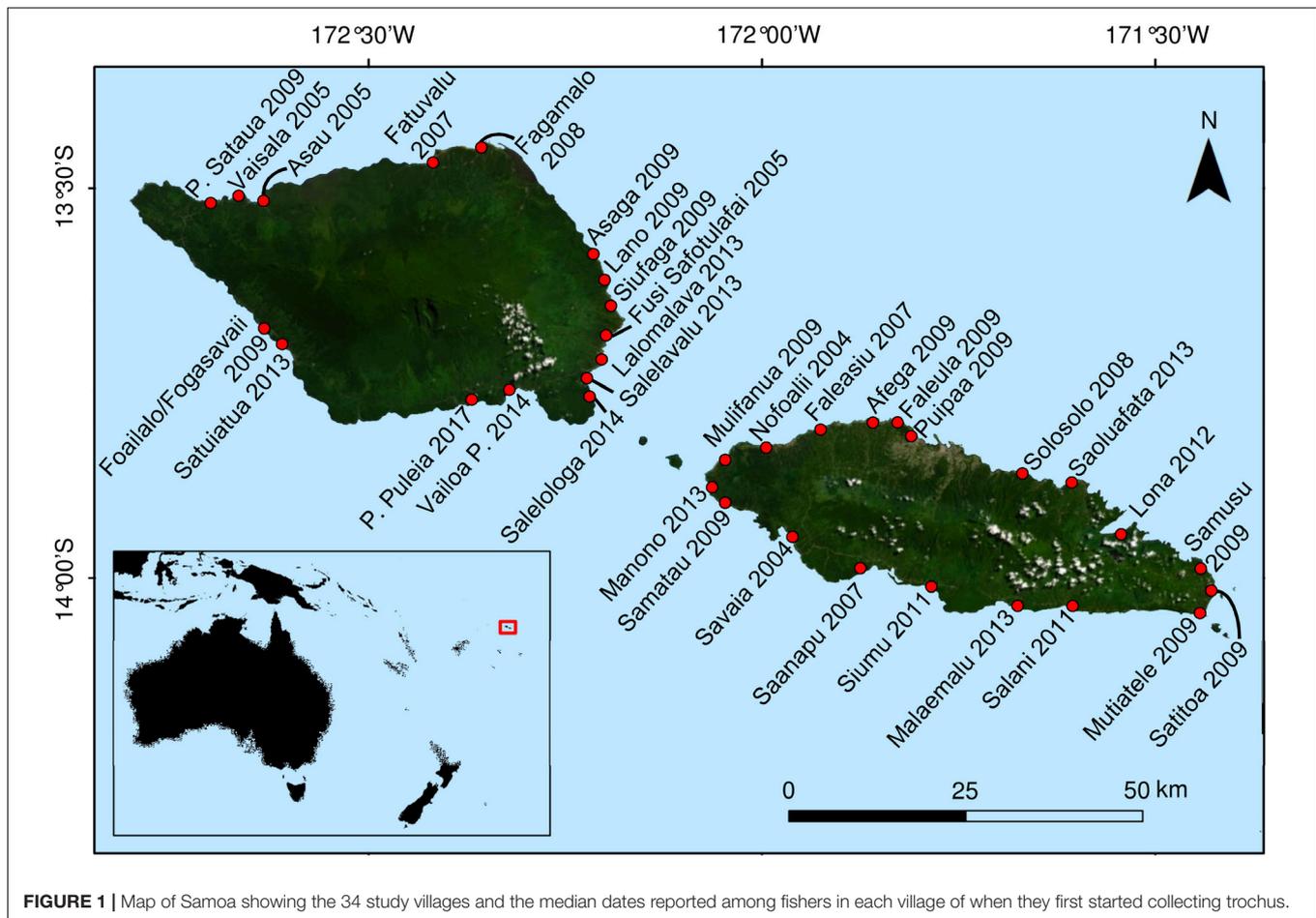


FIGURE 1 | Map of Samoa showing the 34 study villages and the median dates reported among fishers in each village of when they first started collecting trochus.

given to each interviewed fisher, explaining the project, funding, research uses of data, and the voluntarily and confidential nature of the interviews, and we obtained written consent from each interviewee.

Fisher interviews using a structured questionnaire, following guidelines by Kronen et al. (2007), were conducted at either the fishers' homes or in an open place within villages. Both male and female, trained Samoan fishery officers and a foreign researcher (SWP) conducted the interviews on both male and female fishers, with no particular delineation (Figure 2). Interviews took 25–40 min to complete and were facilitated by an interpreter when conducted by a foreign researcher (SWP). A total of 303 fishers were interviewed. At the end of each interview, fishers were invited to offer additional comments or qualitative accounts.

We asked each fisher questions including (but not restricted to): whether they practised gleaning (i.e., wading in shallow waters to collect trochus) or breath-hold diving (hereafter simply termed diving) or both, zones in which trochus were collected, the number of days fishing for trochus per week, the type of boat used (if applicable), travel time to get to/from fishing sites, fishing effort (hours in water fishing), catch on a good day and an average day, rank importance of different marine resources to his/her overall average catch (by volume), perception about the current trend in abundance of trochus stocks, years since

first fishing (hereafter termed fishing experience), his/her views about minimum size limits and seasonal closures for the fishery, and how many trochus fishers she/he thought there were in her/his village. To obtain other potential explanatory covariates, we also recorded their village, gender, age, and responses to other questions about where they sold trochus. The numbers of trochus caught by fishers on a 'good' day were not used for analyses, and was simply asked to provide a reference point to minimize exaggeration by fishers about their catches on an 'average' day. The average-day catch (number of trochus) divided by the fisher's average time spent fishing (excluding travel time) gave the catch-per-unit-effort (CPUE) (modified from Kronen et al., 2007). The average annual harvest yield per fisher was calculated as follows:

$$\text{Annual yield}_{ij} = C_{ij} \times F_{ij} \times (52 - (MN_{ij} * 4.33))$$

where,

Annual yield_{ij} = the estimated total number of trochus collected by fisher i in village j

C_{ij} = catch in number of trochus by fisher i in village j on an average day of fishing

F_{ij} = average number of days per week that fisher i in village j reported going fishing for trochus in the past year

TABLE 1 | Summary of men and women respondents in surveys, with their average age (\pm SD).

Island	Village	<i>n</i>	Men (%)	Women (%)	Avg. age men (\pm SD)	Avg. age women (\pm SD)
Savaii	Asaga	8	100	0	25 (7)	–
	Asau	9	89	11	41 (15)	35
	Fagamalo	9	89	11	41 (11)	50
	Fatuvalu	10	90	10	39 (10)	40
	Foailalo/Fogasavaii	9	78	22	36 (10)	42 (17)
	Fusi Safotulafai	8	100	0	32 (15)	–
	Lalomalava	8	100	0	34 (17)	–
	Lano	11	100	0	41 (13)	–
	Papa Sataua	13	38	62	40 (13)	47 (12)
	Salelavalu	8	88	13	28 (11)	42
	Salelologa	6	83	17	31 (13)	27
	Satuiatua	8	75	25	38 (14)	39 (1)
	Siufaga	10	90	10	45 (8)	50
	Vailoa Palauli	7	71	29	49 (7)	39
	Vaisala	8	75	25	42 (18)	39 (2)
Upolu	Afega	9	100	0	36 (17)	–
	Faleasiu	12	67	33	37 (9)	37 (18)
	Faleu Manono	10	80	20	39 (14)	44 (6)
	Faleula	8	75	25	46 (10)	46 (13)
	Lona	7	71	29	33 (12)	41 (4)
	Malaemalu	10	80	20	42 (11)	31 (3)
	Mulifanua	10	90	10	39 (12)	56
	Mutiatele	11	91	9	36 (14)	50
	Nofoalii	9	89	11	33 (9)	24
	Puipaa	8	75	25	36 (4)	32 (7)
	Saanapu	12	92	8	31 (9)	30
	Salani	7	71	29	54 (9)	45 (4)
	Samatau	11	82	18	27 (10)	23 (6)
	Samusu	9	67	33	34 (12)	5 (18)
	Saoluafata	7	86	14	39 (10)	47
	Satitua	7	86	14	43 (4)	43
	Savaia	7	86	14	48 (10)	28
Siumu	9	89	11	41 (7)	38	
Solosolo	8	100	0	40 (13)	–	

MN_{ij} = months per year that fisher i in village j reported not fishing.

In order to calculate the total yield of trochus and carbon footprint of the fishery, firstly fishery officers of the Ministry of Agriculture and Fisheries collectively gave conservative estimates (i.e., at a minimum) of what they believed would be the number of trochus fishers in coastal village around Upolu and Savaii, given their experience. The sum of the median numbers of fishers reported in each of our study villages (by fishers) was added to the sum of estimates of trochus fishers for other villages for both Upolu and Savaii. Annual yields of trochus per study village were derived by multiplying the average annual yield per fisher in a village (based on the equation above) by the median number of trochus fishers reported by fishers in that village. Annual yields of trochus for the entire fishery were derived by multiplying the average annual yield per fisher in Upolu and Savaii, separately, by the estimated number of trochus fishers on each island. The

carbon footprint of fishing boats used to harvest trochus was estimated by calculating the annual boat fuel use per fisher, using 'recall data' of their last trip, and multiplying by the estimated number of boat users in the fishery.

$$\text{Annual fisher fuel use}_{ij} = \left(\frac{U_{ij}}{S_k + 1} \right) \times F_{ij} \times (52 - (MN_{ij} * 4.33)) \times 2.35$$

where,

$\text{Annual fisher fuel use}_{ij}$ = the estimated annual number of liters of boat fuel used by fisher i in village j

U_{ij} = liters of fuel reported to be used for the boat used by fisher i in village j on their last fishing trip

S_k = number of other fishers in the boat k sharing the cost of boat fuel

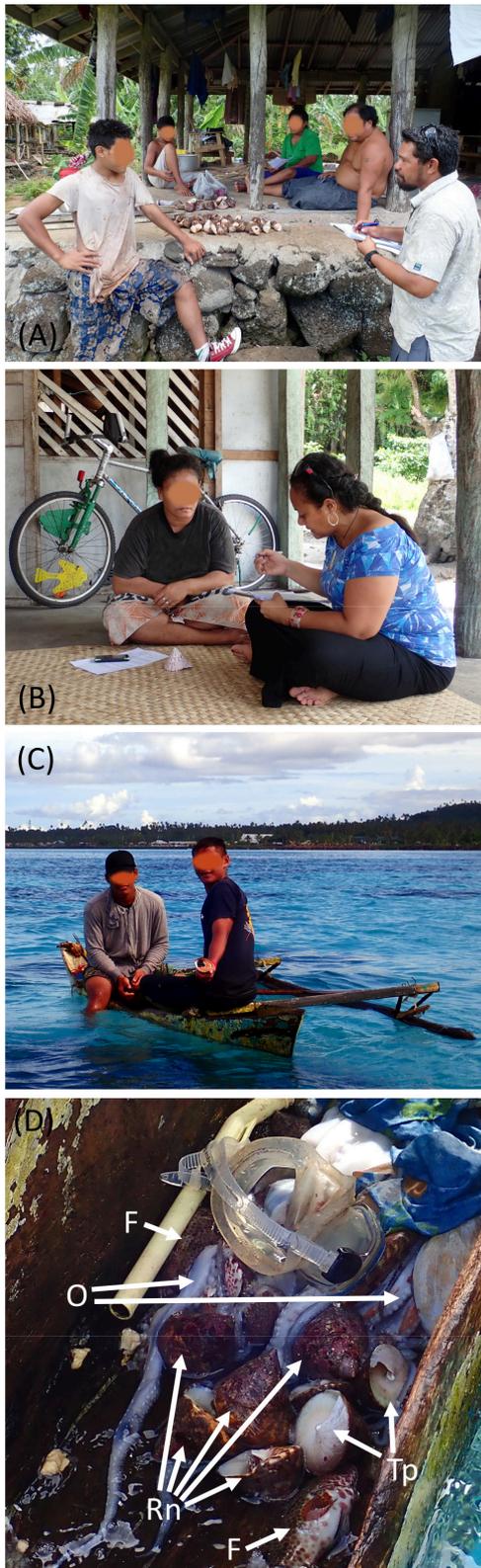


FIGURE 2 | From top to bottom: **(A)** Samoan fishery officer interviewing a young fisherman with his trochus landings and family at the back, **(B)** Samoan (Continued)

FIGURE 2 | Continued

fishery officer interviewing a mid-age fisherwoman, **(C)** traditional Samoan paddling canoe with a diver showing a trochus on his hand, and **(D)** example of a daily catch inside a paddling canoe showing: F, fish; O, octopus; Tp, *Tectus pyramis* (locally called 'aliao Samoa') and Rn, *Rochia nilotica* (trochus). Written informed consent for the publication of these images was obtained from persons for which faces are not blurred.

F_{ij} = average number of days per week that fisher i in village j reported going fishing for trochus in the past year

MN_{ij} = months per year that fisher i in village j reported not fishing

4.33 is the average number of weeks in a month

2.35 is the accepted CO₂ emission per liter of petrol¹.

Statistical Analysis

Data for six response variables were analyzed using the ASReml-R software (Butler et al., 2009) within R (R Development Core Team, 2011). They are listed in **Supplementary Table S1** and were analyzed using either a linear mixed model [LMM; average (mean) days fishing per week, average (mean) trochus per day and average (mean) CPUE] or a generalized linear mixed model [GLMM; rank of importance, number of resources harvested (here termed 'catch diversity') and current trend in trochus stocks], depending on the type of data and distributional assumptions. Explanatory variables were considered to be either primary, that is, of interest in terms of understanding factors affecting fishing by artisanal fishers in Samoa (island, village, gender, and age), or secondary, which are included to reduce error or explain variation [surveyor (i.e., interviewer), fishing strategy, average days fishing per week, hours fishing, years fishing, boat use, and annual fishing costs].

With the exception of surveyor, all secondary terms were fitted as fixed model terms, as well as gender and age and their interaction. Due to the unbalanced nature of socioeconomic data such as in this study, the factors of island, village and surveyor and the interactions of island and village with gender and fisher age were fitted as random model terms. This was to ensure that information on the treatment effects contained within differences between islands, villages, surveyors and their interactions was recovered in forming the estimated treatment effects. Given the aims of the study in considering the variation in fishing, the set of random model terms was not removed from any analysis. Surveyor was fitted as a random model term to capture variation associated with the surveyor effects, resulting in more reliable estimates of the effects of interest and subsequent inference. Possible non-linearity in each response variable due to fisher age, as well as non-linearity in the age by gender interaction, was examined by the inclusion of cubic smoothing spline terms following the approach of Verbyla et al. (1999) and the use of added variable plots (Atkinson, 1985). The penalized quasi-likelihood estimates of the variance components for the smoothing spline terms were on the boundary of the parameter

¹www.epa.gov

space for all response variables and these terms were therefore excluded from all analyses.

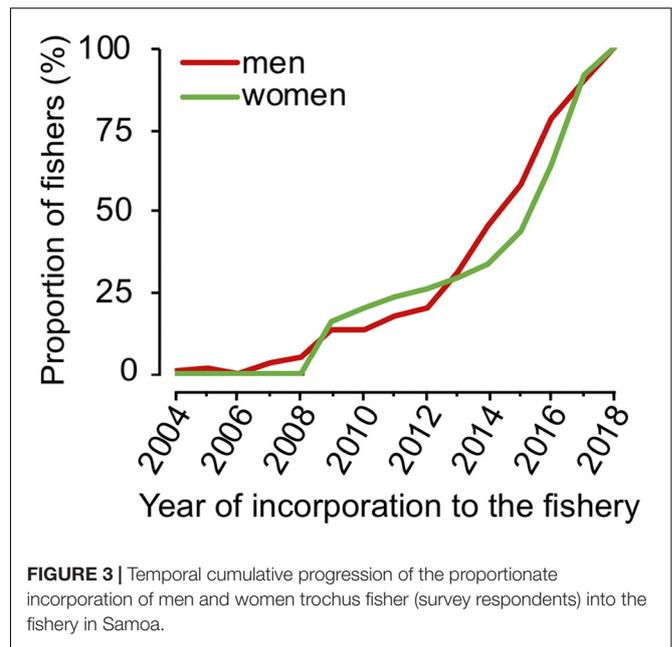
Standard residual plots were used in the three LMM analyses for the purpose of model checking and assessing the data for possible outliers. Due to the large range in average trochus per day and the average CPUE data, these response variables were log-transformed prior to analysis. For the GLMM analyses we used the standardized deviance residuals following Lee et al. (2006). The number of resources harvested represent count data and were analyzed using a Poisson-GLMM with the log link. The current trend in trochus numbers was measured as an ordinal response variable with possible outcomes being decreasing, stable or increasing. They were analyzed using a 2-threshold multinomial ordinal GLMM with the logit link, which represents an extension of the approach of McCullagh and Nelder (1994) to include random effects. Fishers were asked to rank the resources they collect (catch) from most important (the most collected) to least important (the least collected), in terms of physical volume. The ranks for trochus ranged from 4 (the least collected resource) to 10 (the most) and were analyzed using a 6-threshold multinomial ordinal GLMM with the logit link.

RESULTS

Gender and Age of Fishers

Women represented 17% of surveyed fishers ($n = 51$), with their ages ranging from 19 to 65 years. Men represented 83% of surveyed fishers ($n = 252$), and were of similar ages to the surveyed women; range: 16–68 years. Men outnumbered women in our surveys partly because they were the ones that village informants most often told us about, hence it is possible that the contribution of women in the fishery could be greater than represented by our survey because we might not have been directed in villages to interview fisherwomen, particularly those who only collect trochus occasionally.

Across most of the response variables tested, our analyses detected no significant differences among fishers attributable to gender (Wald test, $P > 0.05$). This result arises because other explanatory variables (e.g., boat use, fishing frequency, age, fishing experience) are simultaneously included in the model and their effects on the response variables might explain otherwise seeming disparities between men and women if simply cross-tabulating raw data between men and women only with disregard to other explanatory variables. This is necessary to do when sample sizes of men and women are unbalanced between each subgrouping of the other explanatory variables, as will almost always occur with socioeconomic surveys, and is a more sophisticated approach to ‘poststratification’ within demographic subgroups (see Lee and Forthofer, 2006). Given the non-significant effects of gender in most cases, men and women trochus fishers can be considered to be similar, and are hereafter called fishers collectively, unless specified separately. The age of fishers was found to be a statistically significant effect only in the analysis of rank of importance of trochus to catch composition ($P = 0.002$), yet did not significantly influence variations in



responses among fishers for any other response variable (Wald tests, $P > 0.10$), so this nil effect will not be further reiterated.

Evolution of the Fishery Fishing History

Averages of fishers' responses to the question “how long ago did you first start collecting [the introduced] trochus?” indicated that the fishery initially started in the mid- to late-2000s (Figure 1). At several of the study villages, trochus were only first harvested within the 5 years prior to our surveys.

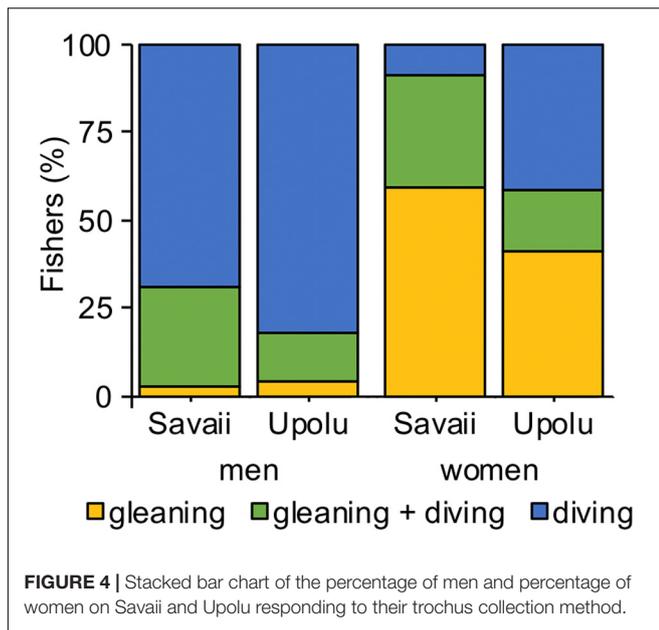
From 2004 to 2008, the engagement of fishers in the trochus fishery was quite limited (Figure 3). In 2009, numerous villages started fishing for trochus. After 2012, the fishery showed a marked growth in entrants. There was no sign of an asymptote in fisher participation rates in the last couple of years prior to our surveys (Figure 3).

Trends in Fishing Activities

Modes of Collection and Carbon Footprint

Samoan fishers collected trochus by hand, and normally stored them in a sack while fishing unless they used a boat and could put the animals straight into it. Fishers could simply walk out in shallow waters from shore to the reef to collect the animals at low tide (i.e., ‘glean’), swim from shore to reefs (dive), or go out in a boat to either dive (breath-hold) on the reef near the boat or wade on reef flats at low tide. However, boat users were more likely to practise diving.

Most fishers captured trochus exclusively using diving as a main method (68%), followed by 21% who alternated between gleaning and diving and 11% who used just gleaning as a fishing method (Figure 4). A greater, yet non-significant, proportion of women practised gleaning than men but many of the women also dived. Few men practised gleaning as a sole fishing mode.



The partial use of gleaning was, for both men and women, more frequent on Savaii island than Upolu.

Twenty-six percent of fishers had no access to a boat (canoe or motor boat), while most of them used a paddling canoe (72%) and 2% used a motorboat (18–40 hp). A smaller non-significant proportion (49%) of women used a canoe or motorboat compared to men (79%). No fisher reported using a traditional sail canoe as a boat.

An annual carbon footprint of the fishery from boat fuel was calculated by extrapolating our data on the percentage of fishers using motor boats and their average annual fuel consumption across the 1037 fishers estimated to be harvesting trochus in Samoa. Since a small proportion of fishers used motor boats, the estimate of 20.4 tonnes of CO₂ (±2.8 tonnes) was calculated for fishery for the 2018 year. This estimate does not include greenhouse gas emissions from cars or buses used by the small proportion of fishers that take their trochus to town markets, but most fishers sold trochus within their villages (Purcell et al., unpublished data).

Travel Times and Fishing Zones

Fishers spent, on average, 48 (±42) min in round-trip travel time to fishing sites, although travel time varied greatly among fishers. For instance, gleaners that collected trochus at the front of their house might spend 10 min wading out to their fishing ground, whereas fishers using a boat to reach remote areas could spend more than 30 min traveling.

Trochus were collected at the front reef slope (25% of fishers), reef flat (15%), reef crest (1%), or combinations of these reef zones (crest and slope = 24%; flat and slope = 19%; all three zones = 10%; flat and crest = 6%).

Fishing Frequency and Effort

Fishers collected trochus, on average, 3.4 d week⁻¹ (±1.6 s.d.), and greater than one in three fishers went fishing for trochus

at least 4 days per week. Most variation in fishing frequency is attributable among individuals within their socio-geographical context (residual error = 85%). Fishers collecting trochus more frequently each week tended to have greater annual costs ($P = 0.01$), for example by spending more money on gloves, sacks and torch batteries, which are consumables dependent on fishing frequency. They dedicated, on average, 3 h (±2) to fishing effort to search for trochus once at the fishing grounds (min = 25 minutes, max = 8 h) (Table 2).

Trends in Harvests and Catch Diversity

Catch Volumes

Daily catches of trochus were significantly ($P = 0.03$) greater for boat users (46 ± 38 trochus d⁻¹) than for fishers without a boat (33 ± 33 trochus d⁻¹). The number of hours fishing per day, average days fishing per week, years of fishing experience and annual fishing costs significantly influenced daily trochus catches ($P < 0.03$). Additionally, differences among villages accounted for a large proportion of variation in daily catch volume (24%).

Annual catch volume for the 2018 year varied greatly among villages (Figure 5). Catch volume was quite modest for the western parts of Savaii. Catch volume tended to be highest on the northern and eastern coasts of Savaii, and along the northern coast of Upolu.

Extrapolating to all the fishers involved in the fishery (~1037 fishers), the number of trochus captured in 2018 was estimated around 7.0 ± 2.3 million trochus. Based on observations of catches of around a dozen fishers, we estimated that around 15–25% of the trochus caught by fishers is above 90 mm basal shell width. We therefore, conservatively, took 15% to be the minimum proportion of catches above this proposed size limit. That proportion of catches, and an average weight of 250 g for shells between 90 and 120 mm, yielded a total exportable weight of 263 tons of trochus shell that were harvested across Samoa for the 2018 year.

Average Catch per Unit of Effort (CPUE)

CPUE (catch-per-unit-effort) was highly variable among fishers. Similar to results observed for daily catch volume, the GLMM showed that boat use significantly affected fishers' average CPUE ($P = 0.003$). Using the back-transformed predicted means, the average CPUE for boat users (12.5 trochus h⁻¹) was five animals per hour greater than fishers without a boat (7.4 trochus h⁻¹) when accounting for other explanatory variables such as gender, age, experience, fishing strategy, and boat use. Capture rates varied greatly among fishers within and between villages, from just 1 trochus h⁻¹ in some villages to 300 trochus h⁻¹ reported in northern Savaii (Fagamalo village). Consequently, villages accounted for 26% of the overall variation in CPUE.

Catch Diversity

Fishers collectively reported harvesting a total of 15 different marine resources. Four fishers only collected trochus, while many others collected trochus and one, two, or more marine resources (e.g., fish, octopus, crabs, giant clam, lobster). The maximum number of resources collected by a single fisher was ten (Figure 6).

TABLE 2 | Summary of the average fishing day per week, travel time, hours fishing for trochus and fishing effort by men and women respondents in surveys (\pm SD).

Island	Gender	Fishing freq. (d week ⁻¹)	Travel time (h)	Hours fishing (h)	Fishing effort (trochus h ⁻¹)
Savaii	Women	2.4 (1.3)	1.2 (0.9)	2.4 (1.4)	11.2 (12.3)
	Men	3.6 (1.6)	0.8 (0.8)	3.2 (1.7)	23.0 (36.6)
Upolu	Women	3.2 (1.4)	0.8 (0.5)	3.1 (1.3)	13.6 (13.6)
	Men	3.4 (1.5)	0.8 (0.6)	3.5 (1.8)	19.0 (28.1)
	Total	3.4 (1.6)	0.8 (0.7)	3.3 (1.7)	19.3 (29.9)

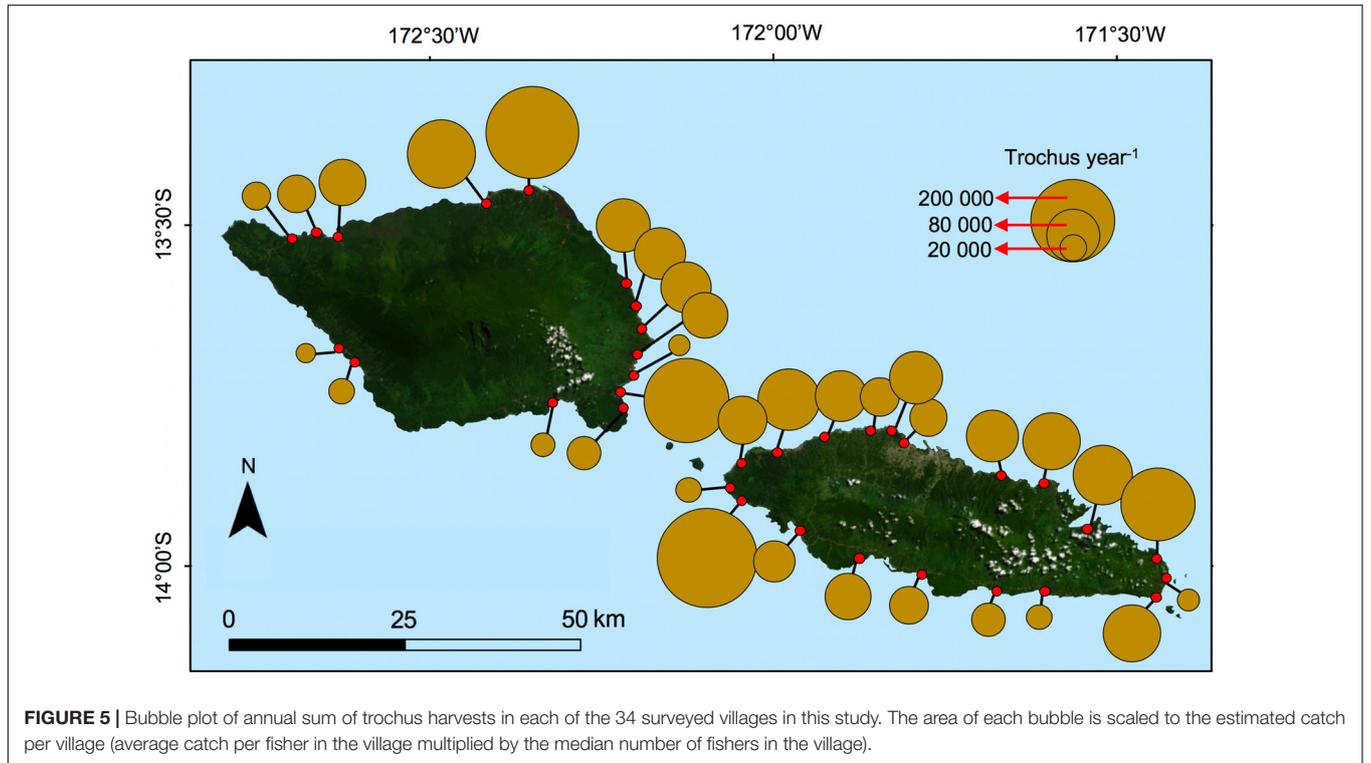


FIGURE 5 | Bubble plot of annual sum of trochus harvests in each of the 34 surveyed villages in this study. The area of each bubble is scaled to the estimated catch per village (average catch per fisher in the village multiplied by the median number of fishers in the village).

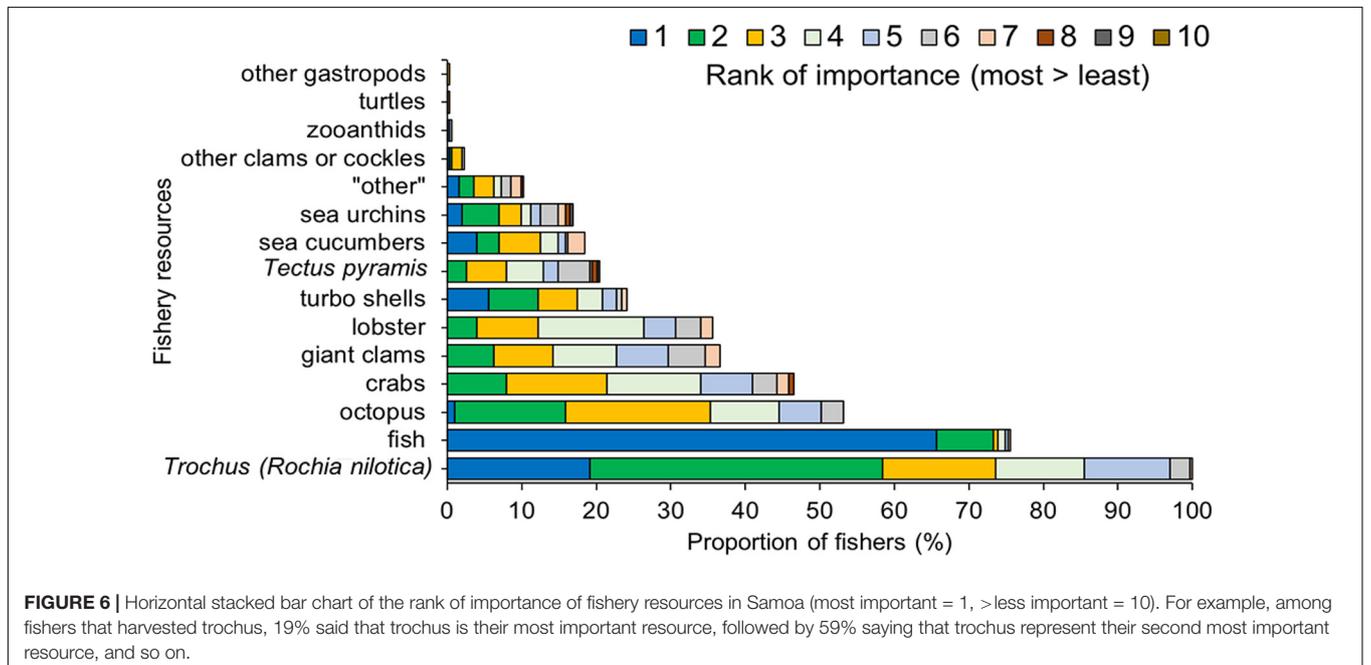


FIGURE 6 | Horizontal stacked bar chart of the rank of importance of fishery resources in Samoa (most important = 1, >less important = 10). For example, among fishers that harvested trochus, 19% said that trochus is their most important resource, followed by 59% saying that trochus represent their second most important resource, and so on.

The fishing method used by fishers significantly influenced catch diversity. Fishers using both gleaning and diving were predicted to collect a significantly larger range of resources (predicted mean: 4.7 resources), than divers (4.0) or gleaners (3.4). Almost all of the variation (97%) in catch diversity among the primary variables was due to differences among individual fishers (i.e., residual variation).

Resource Rank of Importance

Trochus was ranked as the most or second-most harvested resource for 58% of fishers (Figure 6). Gender significantly influenced the importance of trochus to catch volume of fishers ($P = 0.002$), with female fishers being more likely to rank trochus as a more important part of their catches (by volume) than men. Resource preferences also varied considerably among villages (25% of variation).

Finfish represented the most important resource for 68% of fishers that harvest fish among their resources. Notably, just 22% of women reported actually catching fish, whereas 87% of men reported catching fish on at least some trips. Octopus was also an important resource, considered the most or second most important species captured for 16% fishers (Figure 6).

Fisher Perceptions

Current Trends in Stocks

Across all fishers interviewed, 70% believed that the trochus population was increasing, 21% believed that stocks were stable and 9% thought the stocks were declining (Figure 7). Perceptions of trochus stocks varied greatly among villages (44% of variation) and were significantly influenced by fishers' experience ($P = 0.01$); more-experienced fishers were more likely to believe that stocks were increasing than inexperienced fishers.

At the end of the interviews, fishers volunteered relevant comments and questions related to the fishery. Some of their questions relating to trochus stocks include: "can MAF [the Ministry of Agriculture and Fisheries] introduce more trochus?", "is there any chance to do stock enhancement of the native trochus?", "can we have more trochus for farming?". Relevant comments and questions relating to fishing and catches include: "can MAF support the costs of our fishing gear?", "the meat of the introduced trochus is tougher than the native species," "we prefer the introduced trochus because it is bigger than the native topshell and makes it easier to fill a bottle to sell," and "we need a marine reserve area for the future."

Fishery Regulations

Only one fisher said he would be "unhappy" about the imposition of a legal minimum size limit in the trochus fishery. The rest of the fishers (71%) were "okay" with such a regulation (i.e., they had no objection to the imposition of the regulation in this fishery) and 29% "didn't care" (Table 3).

A seasonal closure in the trochus fishery was also strongly favored by fishers. While most (77%) of fishers were "okay" or "did not care" (15%), 8% of fishers said they would be "unhappy" with the regulation (Table 3).

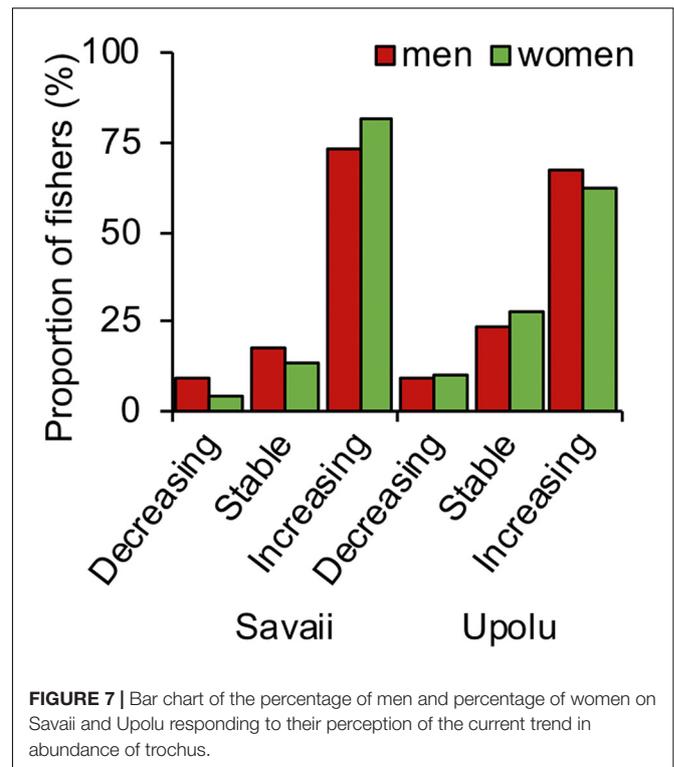


FIGURE 7 | Bar chart of the percentage of men and percentage of women on Savaii and Upolu responding to their perception of the current trend in abundance of trochus.

DISCUSSION

Our study corroborates national market surveys indicating that the trochus fishery in Samoa commenced soon after the stock translocations in 2003–2004, made through foreign-aid funding, and has expanded exponentially over the past decade. The initial slow incorporation of fishers to the fishery might be partly attributed to some socio-cultural factors, such as consumption preferences, but most probably suggests that stocks can take years to develop abundant, fishable populations. Numerous fishers told that the introduced trochus was tougher to eat than the endemic topshell (*Tectus pyramis*, locally called 'Aliao Samoa'), but its larger size would have been attractive to fishers at an early stage in the colonization of populations on reefs.

Understanding Gendered Differences in Fisheries

Fishing activities can be discriminated by gender and age in some SSFs (Siar, 2003; Hauzer et al., 2013). However, we found this was, for many variables, not the case for Samoa's trochus fishery, where both men and women practised gleaning and diving and had comparable fishing frequency and catch-per-unit-effort. Comparable responses between men and women in our study should not be, by any means, taken as 'gender evaporation' (*sensu* Kleiber et al., 2015). In fact, we anticipated gendered disparities in most of the fishing responses, and some large differences would have been apparent between simplistic groupings of men and women if other factors had been neglected.

TABLE 3 | Fishers acceptance response (%) to possible fisheries management regulations: minimum legal-size limit and seasonal closure.

Island	Gender	Size limit			Seasonal closure		
		Unhappy	Don't care	Okay	Unhappy	Don't care	Okay
Savaii	Women	0.0	7	0	1	0	6
	Men	0.3	5	31	2	6	29
Upolu	Women	0.0	1	8	1	1	7
	Men	0.0	9	38	4	8	35
Samoa		0.3	29	71	8	15	77

For example, CPUE of women appears lower on both islands than that of men but the differences are inconsequential when boat use of fishers is accounted for—the differences in that case are about whether the fisher uses a boat, or not, and not their gender roles. Such complexities are commonplace in surveys of resource users, where subjects will rarely be grouped evenly among explanatory factors (Lee and Forthofer, 2006). We also found that women shared similar perceptions to men about the status of trochus stocks. Consequently, gender did not greatly differentiate fishing and knowledge among fishers in this fishery. We did find that trochus were ranked, on average, as significantly more important to the catch volumes of women, which could be reflective of their societal roles in providing for household consumption. But both men and women collected trochus alongside other resources, including finfish. Our results of comparable catch diversity between men and women, therefore, provides a case that dispels the old belief that “fish are for men, shells are for women” (Siar, 2003; Kleiber et al., 2015). Gender similarities observed in this fishery should be considered positively, since gender variation might imply differential access or effects of management regulations (Purcell et al., 2018).

The gendered disparities that we did find were regarding daily catch rates and the relative importance of trochus to catches, which were also dependent on the village of the fishers. Trochus was relatively more important to resources caught by women, whereas men relied less on trochus and more on finfish. CPUE (per hour fishing) was comparable between men and women, and so the disparity in *daily* catch rates arises because women in some villages only went fishing for short periods for direct consumption. Consequently, women had smaller daily catches than men in those villages. This result shows that gender disparities in seafood harvesting can be context-driven at the village scale. This could rise from differences in subsistence or economic needs among villages, such as people in some villages who are further from markets, or in poorer villages, relying more on subsistence harvesting.

Reef gleaners represent around 25% of the six million reef fishers estimated on a global scale (Teh et al., 2013). In Samoa, gleaning is considered by some men as women's activity, which is consistent with the larger number of women using this harvesting mode. Similarly, in other countries women also tend to be gleaners (Furkon and Ambo-Rappe, 2019), but notably in Samoa, many women also practise diving. Since gleaning is frequently undertaken by women and their children, the number of gleaners

is usually underestimated (Teh et al., 2013). These are sensitive data that families might not be willing to share, for example, due to implications of child labor laws (Chuenpagdee et al., 2006). Around 20% of Samoan commercial fishers are reported to be women (Gillett, 2009), yet this proportion will likely be larger when including subsistence fishers.

Substantial overlap in fishing modes and similar fishing frequency and effort between men and women is noteworthy. In some countries, fishing effort can be opportunistic and restricted by tides, sea conditions and resources availability (Hauzer et al., 2013). Women's roles in fisheries can be confined to gleaning, postharvest processing and selling activities (Biswas, 2017; Furkon and Ambo-Rappe, 2019), or they might be excluded from certain fishing, resulting in smaller catches (Chapman, 1987; Hauzer et al., 2013). One must not overlook that in this and other artisanal Pacific Island fisheries, men can also be heavily involved in postharvest processing and selling (MacKeracher et al., 2019; Purcell et al., unpublished data), and could be charged with other tasks such as fabrication and maintenance of paddle canoes. We were told by some fishers that gleaning used to be considered a harvest strategy of women but that men were gleaning more nowadays, and our data supported this assertion. Overall, our data suggest that gender roles might be changing in fisheries and the fishing responses of women can be comparable to that of men in some SSFs. When compared to men, women applied similar fishing effort and had similar catch rates, underscoring the need for their equal representation in decision making about fishery management and development. This could take the form of mandated proportions of fisherwomen in industry representative bodies and consultation meetings, and a gender-inclusive approach (*sensu* Kleiber et al., 2015) in surveys to gauge fisher views for planning management measures.

Fisher Traits Affecting Fishing Effort and Catches

Differences among villages in fishers' access to fishing grounds, and habitats, might easily explain differences in daily catches, CPUE, and importance of trochus in catches among villages. In a parallel study in the same fishing area, we found huge variation in densities of trochus among reefs nearby to the study villages in this study (Purcell and Ceccarelli, unpublished data), revealing that variation in catches among villages is not explained by variation in fishing practices alone.

Access to fishing gears can increase capture rates and be directly related to higher socioeconomic status (Siar, 2003).

In Samoa, boat use was a major determinant of daily catches. The widespread use of paddle canoes rather than motorized boats, as can be the case in other Pacific Island artisanal fisheries (Purcell et al., 2018), makes this trochus fishery quite “green,” with a low carbon footprint for the capture component. Such data on greenhouse gas emission from SSFs in developing nations are especially needed in order to inform global and regional emissions models, helping to “illuminate the role that fisheries have in the environmental cost of global food-production systems” (Parker et al., 2018). We recognize that we only account for emissions from boat fuel and our carbon footprint does not include other sources from the fishery. The estimate of carbon footprint from boat fuel of 18–23 tons of CO₂ per year for the entire fishery in 2018 is miniscule compared to the thousands of tons of CO₂ per year emitted by some other SSFs (Purcell et al., 2018) and most industrial-scale fisheries (Parker and Tyedmers, 2015). The finding implies that huge variation exists among the carbon footprints of different SSFs around the world.

Catch diversity was the only variable that was consistent geographically. Although the importance of trochus to catch volume did vary among villages, fishers in villages around the two main islands caught a similar range of marine resources. The specific access of each village to the different part of the reef (slope, flat, or crest) might be directly associated with the concurrent variance among villages observed across most explanatory variables tested. The catch diversity reported here is similar to that observed for Indonesian gleaners (Furkon and Ambo-Rappe, 2019), although about half of the Samoan gleaners also reported to catch fish. We found that Samoan divers relied more on fish, and gleaners on trochus, which is comparable with other fisheries where gleaners typically rely on shallow-water invertebrates (Purcell et al., 2012; Teh et al., 2013; Prieto-Carolino et al., 2016).

Perspectives on Fishery Management

A formal management plan for the trochus fishery had not yet been implemented at the time of this study. One of the six objectives in the draft management plan is to “Ensure the trochus resource reproduces to its full capacity in Samoa.” The stark increase in the number of fishers collecting trochus after about 2010 might be associated with the perception by a majority of fishers that stocks were still increasing in abundance. Our results showing the propensity for more experienced fishers to believe that trochus stocks were increasing is indicative of their longer-term perspective about stocks when trochus were first becoming colonized on the reefs in Samoa. This observation contrasts with that made in Fiji, where older fishers tended to have a more pessimistic point of view about shellfish stock depletion (Bao and Drew, 2017). Our study shows the potential utility of local ecological knowledge (LEK) of fishers in understanding stock status in artisanal fisheries in which longitudinal data on catches are often lacking (Medeiros et al., 2018). The dramatic increase in participation rates that we report for Samoa’s trochus fishery should be a

concern and stricter management measures might be needed to ensure sustainability.

Trochus are relatively robust to fishing pressure (e.g., fast growing, early onset of maturity, cryptic behavior) but some fisheries have clearly declined due to over-exploitation (Bell et al., 2005; Foale, 2008). In Solomon Islands, a reduction in fishery production of trochus from over 700 trochus t y⁻¹ to around 150 t y⁻¹ is believed to be attributed to over-exploitation of stocks (Lasi, 2010). Similarly, in Western Australia, trochus production reached 135 t y⁻¹ and later plummeted to less than 15 t y⁻¹ due to over harvesting (Saunders, 2001).

A reduction in exports from some Pacific Island countries is partly due to a weaker market for shell buttons since about the turn of the century (Lasi, 2010), although there is still international demand for trochus shells that could make exports from Samoa worthwhile. Two further objectives in the draft management plan are to “Ensure trochus support food security, livelihoods and income generation for our village communities locally” and “Establish an exportable commodity in future.” Assuming, conservatively, that 15% of the total trochus catches in Samoa in 2018 were of an export size (>90 mm), our extrapolation of ~263 t for the annual harvest would be around the median of exports from Pacific Island fisheries (Gillett, 2009).

Trochus fisheries have been variously managed in the Indo-Pacific (e.g., Indonesia, Vanuatu, Cook Island, and Samoa) with regulations such as minimum and maximum size limits, ban periods from 1 to 5 years, limited entry rules and total allowable catch quotas (Cohen and Foale, 2013; Gillett and Tauati, 2018). Among Pacific Island countries, Samoa is recognized as the country that has devoted most effort to estimate their total SSF landings (Gillett, 2009). Samoan fishers are familiar with fishery regulations, and some co-management arrangements and regulations on harvest sizes and spatial closures have been in place since at least 1995 (Lovell et al., 2004). Trochus populations can be relatively easily managed with the right regulatory measures (Foale, 2008). Our observations of large proportions of small trochus (<90 mm BSW) in the catches of fishers gives a rationale for imposing minimum legal-size limits. A minimum legal-size limit and seasonal closures have been widely adopted in other Pacific Island trochus fisheries (Purcell, 2004; Cohen and Foale, 2013). Since the large majority of fishers we interviewed said they would accept a minimum size limit, a minimum legal-size limit of 9 cm, as proposed for the fishery in Samoa, is therefore biologically sensible and deemed to be socially acceptable.

Our data provide a foundation for incorporating fisher views into future fishery regulations. Although relatively few fishers disagreed with seasonal closures (8%), the proportion is much larger than for a proposed minimum legal-size limit. This is likely due to subsistence and economic needs of each fisher throughout the year. Similarly, some of Vanuatu’s villagers disagreed with intermittent closure of the trochus fishery because of financial hardship that it would cause (Johannes, 1998). Our data showed that few fishers only collect trochus as a sole marine resource, and so fishers could be expected to rely on other resources for part of

the year if a seasonal closure was imposed. This would require a more holistic approach to inshore fisheries management wherein seasonal closures, as means to control annual fishing effort, could be alternated among key marine resources.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Southern Cross University. The patients/participants provided their written informed consent to participate in this study. Written informed consent was not obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

SP conceived the research and conducted the fieldwork with Samoan Fisheries officers. SP, BC, BG, and AT analyzed the data. SP, AT, BC, and BG wrote the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fmars.2020.00297/full#supplementary-material>

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